TEMPORAL DYNAMICS OF AUDITORY AND CROSS-MODAL ATTENTION: AN INVESTIGATION OF DUAL-TASK DEFICITS

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Summary

When identifying two masked targets presented in rapid succession, awareness of the second may be reduced when it is presented between 100 and 400 ms after the first. This phenomenon has been termed the *attentional blink* (AB). A wealth of knowledge has been collected regarding performance when both targets are presented visually; however, evidence concerning an auditory analogue has been scarce. Nine experiments presented here demonstrate that the auditory attentional blink (AAB) shares some commonalities with but also has some differences from the visual attentional blink (VAB). Two experiments examined cross-modal dual-task interactions and provide only equivocal evidence for a cross-modal AB.

All eleven experiments demonstrated the influence of non-target (distractor) items upon target detection. It was shown that presenting targets within an ordered distractor sequence was an important pre-requisite for the AAB. In addition, the level of exposure to the distractor sequence before the presentation of the first target (T1) moderated target identification. Increasing practice (incorporating target and distractors) also attenuates the magnitude of the AAB. In a similar vein, targets of a different stimulus set to that of the distractors also attenuate the AAB. Unlike the VAB, introducing a switch in stimulus set between targets increased performance at early SOAs.

For the VAB, very little consideration has been given to items occurring before T1, and the pre-eminent masking role of the +1 item is reflected in all theoretical explanations of the VAB. However, the AAB may rely on items occurring before as well as after the targets. It is well established that the nature of the auditory scene provided by the distractors may change the way that targets are defined and processed. Thus, processing restrictions demonstrated by the AAB may not arise specifically from masking but due to the demands of target extraction from ordered perceptual streams.

For Pat and Ali,

you will both live with me forever

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Table of Contents

Contents

List of Figures

Chapter 1

General introduction

1.1 What is attention?

No single detailed or uncontroversial definition of attention is available; some even argue there is a tendency actively to avoid definition (Styles, 1997). A possible reason lies in the paradoxical nature of the attentional system itself. James (1890) stated, "Everyone knows what attention is" (p.381), but untangling what attention is from the fluid process of consciousness is more difficult. Used freely throughout the English-speaking world, the term 'attention' usually refers to an internal control to focus, i.e. "pay attention", suggesting that we, as humans, are able to select what information we process. Such an ability to choose would suggest there is a limit to the amount of information that can be processed at any one time. These two concepts of *selection* and *capacity limitations* have been the building blocks for the development of ideas concerning definitions of attention as well as questions about how attention operates.

Selection and capacity limitations have been described as two sides of the same 'attentional' coin (Pashler, 1999). Selection, the process of extracting an item of interest from a field of potential stimuli and elevating it to a conscious representation, is a seemingly undeniable factor of human consciousness (Pashler, 1999). The notion of capacity limitations is supported by findings of performance changes in circumstances when more than one task is completed concurrently. Some tasks can be carried out easily one at a time but when attempted simultaneously pose great difficulties. These difficulties can arise due to competition for sensory or processing resources and response selection (Pashler, 1999).

The ability to detect and react to threatening events is an evolutionary necessity. It is well established that the nervous system will automatically orientate processing resources towards threatening events (Öhman, Flykt & Esteves, 2001). This orienting response relies on automatic scanning and analysis of the perceptual field, irrespective of the focus of conscious attention (Pashler, 1998; Treisman, 1988). This preattentive process is considered to be fast and automatic, and to rely primarily on detecting environmental changes (Posner, 1978; Treisman, 1988). When change is detected, further processing is considered to take the form of slower mechanisms that interpret the meaning of events (Treisman, 1988). The point at which the transfer of information occurs between these automatic and controlled mechanisms has fuelled psychological debate for many years (Broadbent, 1958, Deutsch & Deutsch, 1963; Mackay, 1973, Treisman, 1999).

1.1.2 The "Early vs. Late" selection debate

Since the 1950s, there has been considerate disagreement concerning the levels of processing afforded an item before selection occurs. It seems logical that some analysis is required to distinguish a stimulus for selection from the field of available stimuli. The question is whether selection is simply based upon the physical attributes of stimuli, or whether meaning influences selection. One means of answering this question is to examine the level of processing non-selected items receive. Two competing schools of thought emerged initially, hypothesising that selection occurs at an early (Broadbent, 1958) or late (Deutsch & Deutsch, 1963; Mackay, 1973) level of processing. These two theories, although considered antithetical (e.g. Broadbent, 1958 & Deutsch & Deutsch, 1963), do share similarities.

1.1.2.1 Early selection

Broadbent's (1958) Filter theory, also known as the early selection theory, is the first detailed theory of attention. The theory states that all items reaching the sensory system are processed to a point at which their physical attributes (e.g. pitch, location or loudness of an auditory stimulus) are analysed. Due to the limited capacity of later processing stages that assign meaning, the number of items entering these stages is restricted. The initial processing stage that defines physical descriptions is considered free of capacity limitations; information enters the system in parallel and is held in a temporary store, or buffer, for a short period. Then the process of selection occurs, effectively filtering the input. This system is thought to defend the brain against the potential overload of sensory information from the nervous system.

Experimental support for the Filter theory comes from the dichotic listening task and the split-stream paradigm. During the dichotic listening task, participants are presented with two streams of information to different ears and are asked to shadow one stream. That is, to attend to one of the streams while ignoring the other. When participants were asked about the unattended stream, there was no memory for meaning whereas physical parameters, e.g. sex of speaker, intensity and location were noticed (Cherry, 1953). These results suggested that the unattended stream received little or no processing other than the physical properties.

Further evidence from the split-stream paradigm (Broadbent, 1944, 1958) provided support for Broadbent's (1958) Filter theory. The split-stream paradigm involves interspersed presentation of two lists of three digits, with one list played to each ear at a rate of two items/s: participants are required to recall as much information as possible. For example, the sequence 5, 2, 7 might be played to the left ear, and 8, 6, 1 played to the right. Broadbent observed that rather than reporting the numbers by pairs (e.g. 5-8, 2-6, 7-1) as the items were episodically presented, the participants tended to group the numbers in the order of the ear to which they were presented (e.g. 5, 2, 7 then 8, 6, 1). Similar patterns of results were demonstrated when streams were defined by differences in pitch rather than ear (Broadbent, 1958). The account offered by Broadbent for these findings was that because both channels could not be attended to simultaneously, one stream was attended to and consolidated, while the other was stored temporarily in a perceptual buffer and then retrieved, thereby explaining the order effects that were observed.

1.1.2.2 Late selection

Further exploration of the Dichotic listening task and the split-stream paradigms have revealed findings that cannot be explained simply by the early selection theory. When words of a high emotional value (e.g. the participants' name) were added to the unattended stream in the dichotic listening task, participants reported awareness of their presence (Wood & Cowan, 1995). Additional contradictory evidence was provided using the split-stream paradigm with the introduction of a semantic relationship between items, e.g. using the stimuli *mice, one, and cheese* presented to the left ear and *four, eat, two* presented to the right ear (Gray & Wedderburn, 1960). In contrast to reporting items by ear (Broadbent, 1954), participants were likely to group information by meaning; *mice, eat, cheese,* and *four, one, two*.

On the basis of these and related findings, late selection theorists (Deutsch & Deutsch, 1963; Mackay, 1973) proposed a variant of Broadbent's (1958) Filter theory whereby familiar objects are processed without capacity restrictions to the point of semantic description before being selected. Capacity limitations were proposed to arise further along the processing chain. The late selection position suggests that stimuli are processed in parallel to a level forming categorical or semantic descriptions before their selection into consciousness.

Evidence consistent with late selection accounts comes from the Stroop effect (Stroop, 1935b), whereby participants often report or manifest difficulty in naming the colour in which an incompatible colour name is written (Jensen & Rohwer, 1966; MacLeod, 1986; Thurstone, 1944). It is hypothesised that the colour denoted by the word creates a verbal representation and that this creates competition for the accurate naming of the colour in which the word is presented (Singer et al., 1975). This is incompatible with early selection accounts since according to this view meaning is interfering with a perceptual judgment. Additionally, this effect is very resistant to practice (Kahneman & Henik, 1981) suggesting that it is at least to some extent 'hardwired'.

An alternative to the preceding accounts is that processing of the to-be-rejected or irrelevant information is attenuated depending upon the type and amount of incoming information (Treisman, 1960). This theory suggests that the selection of items occurs when sufficient detector units are recruited. Rejected items do not acquire enough detector units to exceed a threshold within a given detector. Lavie and Tsal (1994) expanded upon this idea by suggesting that the locus of visual selection may not be either early or late but may depend on the perceptual load imposed by the stimuli. The level to which the primary task consumes the available resources determines the level of processing afforded irrelevant stimuli (Lavie, 1995; Treisman & Riley, 1969; Tsal & Lavie, 1995). In addition, the extent of processing of irrelevant stimuli does not depend upon participants' expectations or intentions to ignore distracting stimuli (Theeuwes, Kramer & Belopolsky, 2004).

1.2 Attentional paradigms

From initial experiments with simple reaction times (e.g. as measured by the dropping of a ruler between thumb and index finger) through to electrophysiological investigations, the ways in which we test behaviour have mirrored technological developments. Early attentional investigations typically utilised single stimuli with either little or no selection criteria (e.g. Swets 1964). The development of dual-task paradigms e.g. split-stream, dual speeded response and rapid serial visual presentation (RSVP) tasks has led to a plethora of theories accounting for dual-task interference (Shiffrin & Gardener, 1972; Turvey 1973). Dual-task interference refers to the reduction of performance on one task due to the competition imposed by the implementation of another enforced task (Pashler, 1998). Several effects, such as the psychological refractory period (PRP) (Gottsdanker & Stelmach, 1971; Pashler & Baylis, 1991) and the attentional blink (AB) (Raymond, Shapiro & Arnell, 1992) have proved very informative as to the nature of the attentional system as well as providing information about the time courses and capacity limitations of human information processing.

1.2.1 Divided attention

The simultaneous processing of more than one stimulus must be subject to capacity limitations if reaction time or accuracy is negatively affected, when compared to the subsequent processing of the same items one-at-a-time (Pashler, 1998). These concurrent processing deficits can be seen if a person is asked to pat their head and rub their stomach; confusion ensues. The tasks, however, are easily completed if they are attempted separately. The integration of these tasks and any attending behavioural costs highlights processing pathways and locations at which competition for limited resources occurs (Pashler, 1998). Dual-task interference presumably arises from competition at the point of information transfer from parallel (high capacity) systems to serial (limited competition) processes (Pashler, 1998; Treisman, 1988). The focus in this thesis is on variants of the RSVP paradigm, and as a result, the RSVP paradigm and important findings are discussed in detail below.

1.2.2 RSVP techniques

One method of investigating the temporal properties of the attentional system is to utilise an RSVP procedure. An RSVP procedure involves rapid presentation of successive items such as letters (Raymond, Shapiro & Arnell, 1992), digits (Weichselgartner & Sperling, 1987), words (Broadbent & Broadbent, 1987) or pictures (Shapiro, 2001) in either the same or different locations. Items are typically presented at rates of between 6 and 30 items/s (Lawrence 1971). The items may immediately succeed each other, or the offset of the previous items may be followed by a non-patterned inter-stimulus interval (ISI) (Shapiro & Raymond, 1994). The stimulus onset asynchrony (SOA) determines the temporal distance between the onsets of items, inclusive of any ISIs. A typical RSVP sequence contains around 15 to 20 items, each item being different from the previous item (although this is not the case when investigating Repetition Blindness (Kanwisher 1987); this will be discussed further in section 1.3.2). Target(s) are differentiated in some way from other items, for example by letter case, colour or a simultaneous change in background illumination. The observer must identify the target or the target-defining feature. Manipulating the number of target items within each sequence allows control over task demands. Non-target items are commonly referred to as distractors.

1.2.2.1 Single-task RSVP

Lawrence (1971) carried out the initial RSVP study in order to track the time course of events succeeding target selection. An uppercase target word was embedded in a random position within a sequence (a stream) of lowercase distractor words (see Figure 1.1). The task for the observer was to identify the capitalised word, which appeared at differing serial positions within RSVPs. Sequences were presented at rates of between 6-20 items/s, with identification performance decreasing proportionally with increasing presentation rate. A very high proportion of these errors were post-target intrusions, whereby the participant would mistake the identity of the target items as being that of the uncapitalised item that immediately followed the target.

The data from this RSVP study leads to the question: can the intrusions be attributed to a sensory or an attentional limitation? Essentially, does the sensory system process the two items as one due to speed of presentation, or do intrusions result from a bottleneck arising from attentional selection? Evidence from masking studies, in which only target and mask are presented, showed no significant decrements in target identification with a target presented for ~ 10 ms and a target-mask SOA of ~ 30 ms (Taylor & Chabot, 1978). Lawrence (1971) presented targets within a stream of stimuli and showed significant performance degradation at a much slower rate of 7 items/s (SOA = 142 ms).

The attribution of the effect to an attentional rather than a sensory limitation led to the development of a two-stage filtering model. The initial early selection stage is activated when the target is detected. This is followed by a subsequent processing stage that identifies the to-be-reported feature from items within the sensory store

(Broadbent & Broadbent, 1987; Lawrence, 1981). According to this account, intrusions are due to the serial and (relatively) slower nature of the second stage.

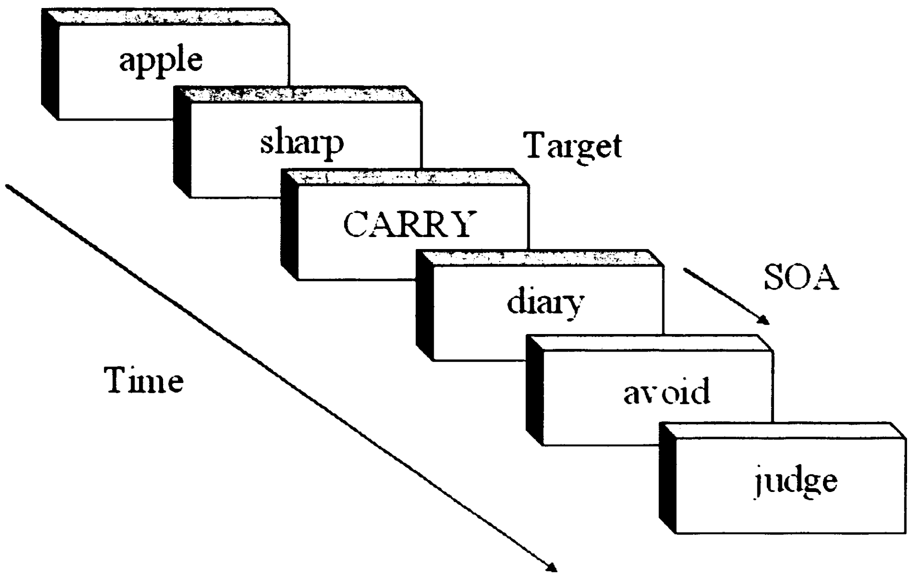

Figure 1.1: Graphic representation of the single-task RSVP procedure used by Lawrence (1971)

1.2.2.2 Dual-task RSVP

Dual-task RSVP paradigms permit further examination of the time-course of events occurring after the presentation of a single target. Broadbent and Broadbent's (1987) dual-task paradigm consisted of uppercase target words that were flanked by hyphens embedded within a stream of unrelated lowercase words. There were two target words in each stream and items within the stream were separated by an SOA of 80ms. Processing deficits were examined by comparing performance for responses made for both targets, and the first target (T1) and the second target (T2) independently. When the two targets were presented in successive serial positions, participants could correctly identify T1 or T2 individually but were markedly poorer when required to identify both. The likelihood of correctly identifying T2 after correctly identifying T1 increased as the number of intervening items increased. The probability of correctly identifying both targets when presented within 400 ms of each other was ~0.1 then increased before reaching asymptote at 0.7 with a T1-T2 SOA of 720 ms or longer (Broadbent & Broadbent, 1987).

These data were interpreted as a demonstration of persistent interference influencing the attentional capture mechanism. According to this account, and as described above, the initial detection of the featural aspect of the targets occurs rapidly then activates a slower capture process which is temporally limited, so processing of T2 is compromised if it occurs in close proximity to T1 (Broadbent & Broadbent, 1987).

1.2.2.3 Multiple-task RSVP

Weichselgartner and Sperling (1987) used a multiple-task RSVP procedure in which they tested highly practiced participants. The participants observed a rapid succession of digits presented in the same spatial location. One target item (distinguished by a change in luminescence or the outline of a square) prompted the participants to identify the target and the three following items. Participants were able to identify the target and the item directly succeeding the target with a high degree of accuracy, along with items presented 300-400 ms after the initial target. Items occurring between 100–300 ms post-target were rarely reported correctly. This offered further evidence supporting the notion of a temporally specific suppression of attentional capture mechanisms.

Weichselgartner and Sperling (1987) proposed that two attentional mechanisms were activated upon detection of the initial target. The first is automatic, unaffected by task difficulty, and lasts for around 100 ms (thus sometimes capturing more than one item). The second is effortful and sluggish, and lasts for between 200 and 300 ms. It is the second of these mechanisms that Weichselgartner and Sperling have suggested as being responsible for their findings, in much the same way as described above for the findings of Broadbent & Broadbent (1987).

1.3. Phenomena elicited by the RSVP procedure

The preceding examples illustrate how the RSVP procedure has been used to investigate the limitations of perceptual and cognitive processes related to attention, response selection and processing in visual short-term memory (VSTM). Variants of the RSVP have also revealed other important effects that are related to the findings described above, and which are relevant to the work that will be described in this thesis.

1.3.1 Repetition Blindness (RB)

Temporary impairments in detection of repeated items within the RSVP have been documented by Kanwisher (1987) and Kanwisher and Potter (1989, 1990). In these initial experiments, participants saw letters presented one item at a time that made up a word. Participants were asked to remember each item in order and report the word in full after each trial. In half of the trials, a letter within the sequence was repeated, and often participants would omit the repeated letter in their subsequent report. This omission occurred even if this affected the correct spelling of the word. The effect has been extended to the presentation of entire words, where the task required observers to detect the repetitions of a word. Rates of presentation of 5.4 and 8.5 items/s reduced the probability of detecting the repeated word if it was presented between approximately 150 and 750 ms after the previous word.

RB effects share a similar time-course to the dual-task RSVP effects described above; the onset and offset of the performance decrement ranges from 150 to 500ms, although the RB effect can have a more prolonged deficit (Kanwisher & Potter, 1989, 1990). However, the two differ in that the dual-task RSVP procedure allows partial and full definition of the target, i.e. the physical properties of the target (partial definition) and the actual semantic property of the target (full definition). The target in the RB can only be the 'repeated item'. Another difference is that of the maximum performance decrement recorded. The dual-task RSVP typically elicits a deficit of c.50% whilst RB has demonstrated a decrement of up to and above 80% (Shapiro & Raymond, 1994). This increased deficit observed during the RB procedure is attributed to the sustained monitoring of the whole sequence as the repeated item could occur at any point in the sequence. The dual-task RSVP, by contrast, requires the detection of two target items and after that; the participant is not required to monitor the sequence.

The essential and fundamental difference between the AB and RB relates to target-distractor (T-D) discriminability. The RB relies on the use of an exact replication of a token and the RB is the inability to distinguish the repeated item as a different event. The AB is moderated by T-D dissimilarity, whereby the resulting processing deficit is most likely due to competition between two separate events (the correctly identified targets).

1.3.2 Dual speeded responses: The PRP effect

The psychological refractory period (PRP) phenomenon is observed in tasks where the participant is required to make speeded responses to two simple, contiguous and similar stimuli. The performance measurement is time taken to react to each stimulus. Generally, reaction time for completing the second task is greater if the SOA is small. The time taken to react to the first stimulus is usually unaffected. In addition, the overall time for the task takes significantly longer than completing each task separately (Pashler, 1998). The term 'psychological refractory period' was adopted due to supposed similarities to the refractory period of neurons.

The dual speeded response paradigm differs from the dual-task RSVP in two major ways. The first is that the stimuli are not presented within a stream of distractors, thus the restriction to processing imposed by masking is replaced by the requirement to make a speeded response. The second is that the PRP appears robust when the stimuli are presented across different modalities (Pashler, 1998), whereas this has not been established for work in which the RSVP has been extended to cross-modal stimulus streams. The PRP does however, share similarities with the RSVP: both phenomena result from the processing of two target stimuli in rapid succession. In addition, the second target suffers from the concurrent processing of the first target and shows a gradual increase in performance with the increase in SOA, whereas performance for the first task is largely unaffected (Jolicoeur, 1999).

1.3.3 The Attentional Blink

With an adapted and simplified technique based on both Weichselgartner and Sperling (1987) and Broadbent and Broadbent's (1987) previous work, Raymond et al. (1992) measured and defined the attentional blink (AB). 16 to 24 letters were presented one at a time and in the same spatial location, with an SOA of 90 ms (15 ms stimulus presentation plus 75 ms ISI) on a grey background (as in Weichselgartner & Sperling, 1987) (Raymond et al., 1992). For the dual-task (or divided attention) condition participants were required to report the identity of two target letters within a stream after the sequence had finished (as in Broadbent & Broadbent, 1987). The first target (T1) was white (all other stimuli were black) and could be any letter of the alphabet, except 'X'. The second target (T2) was an 'X' and was presented on 50% of the trials. At the end of each trial participants had to report the identity of T1 and report whether or not T2 was present. T2 was presented with a varying stimulus onset asynchrony (SOA) with targets separated by non-target (distractor) items. The use of the SOA manipulation allows measurement of performance changes according to the T1-T2 interval (Shapiro, 2001). The single-task (or focused attention) condition required report on the presence/absence of T2 only.

The performance curve described by Raymond et al. (1992) (see Fig. 1.2) highlights the T1-T2 relationship and has been replicated many times with a variety of stimuli (words, letters & digits e.g., Chun & Potter, 1995; Raymond et al., 1992; Shapiro, Raymond & Arnell, 1994). Performance in the divided attention condition is typically calculated as the probability of correctly identifying T2 given a correct response to T1. For the focused attention condition, when only one target requires a response, there is typically no SOA dependent effect. The divided attention condition demonstrates a loss in the ability to identify T2 correctly when presented between 100 ms and 500 ms after the correct identification of T1. With the presentation of T1 and T2 in temporally adjacent serial positions (lag 1), performance is usually very high (although see Visser, Bischof & Di Lollo, 1999). This 'lag 1 sparing' (Chun & Potter, 1995) will be discussed in section 1.4.1.3. As the focus is on the AB in the majority of this thesis, in the following sections a detailed account of the phenomenon is provided.

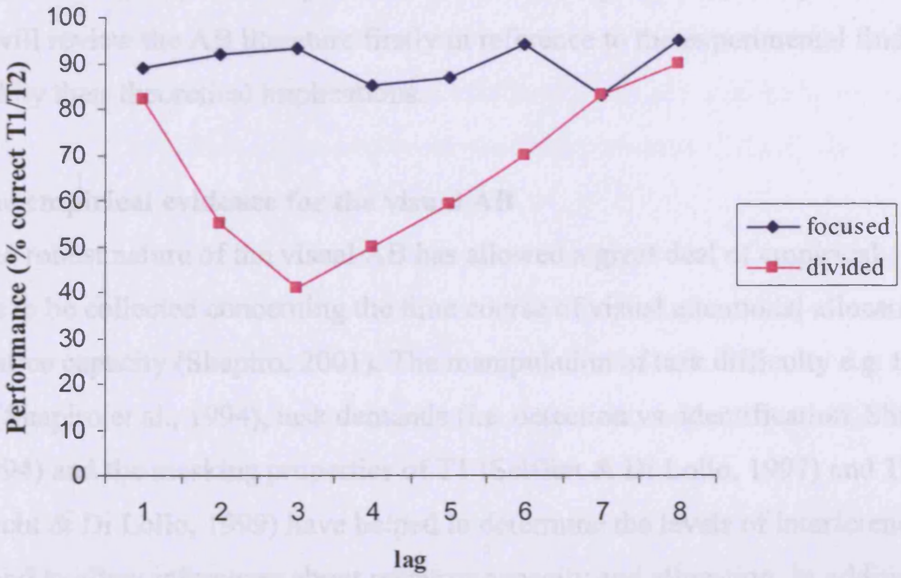

Figure 1.2: Performance for both focused and divided conditions, taken from Experiment 2 of Raymond et al. (1992).

1.4 A review of visual AB literature

Initial findings from single-task RSVP experiments (e.g. Broadbent & Broadbent, 1987; Lawrence, 1971;) were expanded by the creation of two-target RSVP procedures (first reported by Weichselgartner & Sperling, 1987, and developed by Raymond et al., 1992). Raymond et al (1992) provided an initial description of the AB, in both name and behaviour. The AB was initially likened to an eye blink, in as much as the identification of T1 was assumed to have completely tied up the attentional resources, thereby preventing the subsequent processing of any aspect of T2 (Raymond et al., 1992). However, this proposition is problematic for at least two reasons. First, performance at the critical lags did not fall to zero (see Fig. 1.2), ruling out an all-or-nothing process. Second, there is now good evidence that T2 is processed at a post-perceptual level (Shapiro, Arnell & Raymond, 1997; Vogel, Luck & Shapiro, 1997; Luck, Vogel & Shapiro, 1996). Initial research into the AB also highlighted the importance of backward masking of T1 and T2 by the presentation of a contiguous item (either target or distractor for T1): the '+1 item' (Raymond et al., 1992; Seiffert & Di Lollo, 1997). The presence of these masks are thought to restrict processing allocation (Chun & Potter, 1995; Enns, Visser, Kawahara & Di Lollo, 2001; Giesbrecht & Di Lollo, 1999 Raymond et al., 1992; Shapiro et al., 1994). The next section will review the AB literature firstly in reference to the experimental findings, followed by their theoretical implications.

1.4.1 The empirical evidence for the visual AB

The robust nature of the visual AB has allowed a great deal of empirical evidence to be collected concerning the time course of visual attentional allocation and resource capacity (Shapiro, 2001). The manipulation of task difficulty e.g. target set size (Shapiro et al., 1994), task demands (i.e. detection vs. identification, Shapiro et al., 1994) and the masking properties of T1 (Seiffert & Di Lollo, 1997) and T2 (Giesbrecht & Di Lollo, 1999) have helped to determine the levels of interference in VSTM and to allow inferences about resource capacity and allocation. In addition, the phenomenon of 'lag 1 sparing' Chun et al. 1998; Enns et al. 2001; Visser, Bischof and Di Lollo, 1999) will be discussed, as it is a central issue in this thesis.

1.4.1.1 Task difficulty

The relationship between the difficulty of target processing and the visual AB has generated considerable debate (Chun & Potter, 1995; Seiffert & Di Lollo, 1997; Shapiro et al., 1994; Ward, Duncan & Shapiro, 1996, 1997). Techniques have been employed to modulate the difficulty of correct target identification, in particular set size and task demands. Lessening the task demands by reducing the number of potential targets from 25 to 3 produced only a slight reduction in AB magnitude (Shapiro et al, 1994, Exp. 1). In addition, reducing the task demands even further by requesting participants to merely detect the presence or absence of the same target (a black 'X') on every trial (Experiments 3A, 3B, 4, 5A, 5B in the study by Shapiro et al.) rather than identifying one of three letters, demonstrated a sizable AB. Moreover, increasing the difficulty of the T2 task by imposing two separate demands (the participants had to report both relative size and identity of the target) produced a reliable AB deficit; however, performance in both critical conditions (divided attention plus control) was reduced (Ward et al., 1997).

Further research has supported a link between the AB and task difficulty (Chun & Potter, 1995; Seiffert & Di Lollo, 1997). The implementation of a meta-analytic approach incorporating data from 27 AB experiments identified correlations between accuracy and magnitude by increasing statistical power (Seiffert & Di Lollo, 1997). The analysis revealed a negative correlation ($r = -0.73, p<.001$) between target accuracy and AB size. Therefore, while the effects of difficulty may be small in any given experiment, overall it appears to be the case that the more difficult the task of target identification, the larger the AB magnitude.

The difficulty of target identification is also moderated by target-distractor (T-D) similarity (Chun & Potter, 1995). Maintaining similar task demands –thus imposing similar cognitive demands- and increasing the T-D similarity, makes the targets harder to discriminate from the distractors, thus eliciting a larger AB (Chun & Potter, 1995).

1.4.1.2 Masking and the visual AB

Visual masking refers to the reduction in the visibility of one stimulus, the target, by spatially overlapping or contiguous presentation of a second stimulus, known as a mask (Breitmeyer 1984). Masks can be broadly categorised into two distinct groups, those that contain patterns which overlap the pattern of the target in space (pattern masking), and those that do not (structure and metacontrast masking) (Breitmeyer, 1984). Pattern masking can impose two main types of spatiotemporal interference: simultaneous (integration masking) and non-simultaneous (interruption masking). Integration masking adds noise to the target by superimposing additional pattern information on the target. Interruption masking refers to the presentation of a non-target item in a temporally adjacent serial position either before (forward masking), or after (backward masking) the target. Pattern masking is the form of masking most relevant to AB research.

1.4.1.2.1 Masking of T1

Extensive investigation into the role of visual masking within the AB has produced varying results (Enns et al., 2001; McLaughlin, Shore & Kline, 2001; Seiffert & Di Lollo, 1997). One regularity is the importance of the items immediately following the target (e.g. the T1 +1 & the T2 +1 items; the number denotes item position in the post-target stream), whereby replacing the +1 items with blank intervals abolishes the AB (Raymond et al. 1992, Experiment 3). Additionally, increasing or decreasing spatial or featural similarity between the target and the +1 items modulates the amount of interference: reducing the similarity attenuated the size of the AB (Shapiro & Raymond, 1994),

The role of the T1 mask has also been investigated by superimposing a mask upon T1 whilst replacing the T1 +1 item with a blank interval (Seiffert and Di Lollo, 1997). A large AB was obtained with this integration mask when compared to the presentation of T1 with no T1+1 item. Removing the spatial superimposition, moreover, by presenting the T1+1 item in a location adjacent to T1, was enough to elicit the AB to a greater extent than if T1 was not masked at all (Grandison, Ghirardelli & Egeth, 1997; Seiffert and Di Lollo, 1997). These findings led to the conclusion that it is essential that T1 be masked to produce an AB, but with what or when, is unimportant (Enns et al. 2001).

1.4.1.2.2 Masking for T2

Masking of T2, like T1, may be critical for the production of the AB deficit (Raymond et al., 1992), but there are important differences for T1 and T2 masking (Enns et al., 2001). Only interruption masking of T2 elicits the characteristic AB effect (Raymond, et al., 1992; Shapiro et al., 1994; Seiffert & Di Lollo, 1997).

Integration masking produces a deficit in identification, however in this case T1-T2 SOA did not affect performance (Enns, et al., 2001; Seiffert & Di Lollo, 1997). Presenting the mask and target synchronously produced a deficit in performance, but no T1-T2 SOA interaction. Delaying the mask onset (e.g. presenting the mask after 60 ms with an RSVP SOA of 90 ms) produces an SOA dependent effect, however the effect is smaller than if the mask onset occurs directly after the target (target-mask interval is 90 ms).

Interruption masking occurs naturally within the RSVP procedure. The serial nature of dual-task RSVP imposes an additive cognitive demand; therefore, the representation for T2 is presumably more sensitive to interference than is T1. An assumption common in the visual AB literature is that the processing of T1 delays the processing of T2, thereby increasing its susceptibility to competition and subsequent decay (Chun & Potter, 1995). By increasing the time between T1 and T2 presentation, accuracy is increased, producing the asymptotic SOA interaction. The explanation for the findings for integration masking is that this always results in an impoverished representation and therefore does not show any time dependent relationships (Enns et al., 2001).

Further investigations have attempted to differentiate the essential properties required to mask T2 effectively (Enns et al., 2001; Giesbrecht & Di Lollo, 1998). A range of methodologies have been employed: presenting unique items as the +1 items (e.g. digit targets and distractors with mathematic symbols for the +1 items) (Giesbrecht & Di Lollo, 1998) and varying target-distractor (T-D) similarity (Maki, Couture, et al., 1997; Maki, Bussard, Lopez & Digby, 2003). These have served to highlight the T2 and T2 +1 item relationship. Presenting a dot pattern in the T2 +1 position attenuates the AB (Shapiro et al., 1994). Reducing T-D similarity e.g. presenting letter targets within digit distractor streams (Maki, et al., 1997; Raymond, et al., 1994) produces a large AB deficit. In addition, using false font (e.g. mathematical symbols, e.g. 'ψ') distractors with coloured letter targets (T1 = red, T2 = green) produced a substantially attenuated AB curve (Maki, et al., 1997, 2003).

In summary, the influence of interruption masking of the T2 +1 item relates to the degree of interference it exerts upon T2. However, to elicit the AB the T2 +1 item must share a similar pattern arrangement and the effect will persist even with the removal of semantic information (Enns, 2001).

1.4.1.3 Lag 1 sparing

Lag 1 sparing has been attributed to the sluggish closing of the attentional window (Chun & Potter, 1995; Raymond, et al., 1992; Shapiro et al, 1994; Weichselgartner & Sperling, 1987). The gate is said to open rapidly with the presentation of the first target, but closes over a certain period. This sluggish closing allows T2 to enter alongside T1 if it occurs directly after T1, thereby explaining the lag 1 effect. The notion of a sluggish attentional gate is very similar to the idea of a discrete attentional episode, or window that opens for 150-200 ms (Weichselgartner & Sperling, 1995). Thus, lag 1 sparing can be thought of as the incorporation of both targets within the same attentional episode. This gate has been linked to the functioning of the locus coeruleus, a brainstem nucleus, whereby items occurring directly after T1 benefit from the noradrenergic potentiation associated with T1 (Nieuwenhuis, Gilzenrat, Holmes & Cohen, 2005). The positive noradrenergic action resulting from the identification of T1 dissipates slowly, thereby increasing the likelihood of the noradrenergic benefit influencing positively T2 identification.

While it might be assumed that lag 1 sparing is an important component of what constitutes an AB, the lack of lag 1 sparing, perhaps surprisingly, does not attract concern in many studies. Lag 1 sparing is present in some apparently similar AB studies but not in others (e.g. Chun & Potter, 1995; Joseph, Chun & Nakayama, 1997). From one perspective, this would suggest that factors other than temporal contiguity define attentional episodes of sequentially processed items (Enns et al, 2001). It has been assumed either that the absence of lag 1 sparing highlights a breakdown in the attentional process or that the targets are treated as separate attentional episodes (Chun et al. 1998; Enns et al. 2001; Visser, Bischof and Di Lollo, 1999). The presence or absence of lag 1 sparing would therefore allow further examination of what constitutes an attentional episode, in both spatial and temporal domains.

1.4.1.3.1 Attentional switching and Lag 1 sparing

An attentional switch refers to the reassigning of attention resources from one episode to another which exceeds the 'normal' parameters, spatial, temporal or featural of the initial event. The notion of an attentional switch has been implicated in the production of lag 1 sparing. Therefore, what differs between studies that show lag 1 sparing and those that do not? A comprehensive and systematic examination of AB studies since Raymond et al's (1992) initial work was carried out by Visser et al.

(1999), investigating experimental evidence for lag 1 sparing. Studies were included in which significant ABs were found and where the experimental design allowed T2 to be presented at lag 1, approximately 100 ms after the presentation of T1. Lag 1 sparing was defined as a level of performance at lag 1 that was 5% higher than that of the lowest level. The included studies involved a variety of different manipulations, including location, modality, task (identify/detect) and category (letters/digits).

The major finding was that lag 1 sparing was demonstrated with no switching of attentional set between T1 and T2 i.e. both the targets belonged to the same stimulus category (Chun & Potter, 1995; Raymond et al, 1992). In addition, targets needed to be presented in the same modality (Potter, Chun, Banks & Muckenhoupt, 1998), in the same location (Allport et al, 1994; Duncan et al, 1994, Experiment 2, 1997, Experiment 2), or the task for both targets had to be the same (Broadbent & Broadbent, 1987; Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Maki, Couture et al, 1997; Raymond et al, 1992, 1994). Out of those studies that employed multiple switches, 91% of those did not demonstrate lag 1 sparing. As noted by Visser et al. (1999), switches in either task or category alone produced lag 1 sparing in 76% of cases whilst implementation of two switches concurrently demonstrated lag 1 sparing in only 18% of studies.

Lag 1 sparing was not found with a switch in location, as already noted, suggesting that changes in spatial location exert somewhat different influences over when successive targets will be integrated within the same attentional episode. Changing task demands still demonstrated Lag 1 sparing, however, the effect was removed when T1 and T2 were presented in different modalities.

Lag 1 sparing can only be shown when not employing an attentional switch, which can be neatly explained by attentional episode theory (Weichselgartner & Sperling, 1987). However, a revised theory is required to explain studies in which lag 1 sparing is not shown. Visser et al. (1999) proposed a filter based mechanism, an idea that developed from the notion of templates (Raymond, et al., 1992). According to this account, target representations must satisfy a filter based on the processing requirements and the resources allocated to a given task (Raymond et al., 1992; Visser et al. 1999). The filter is not considered target specific, as highlighted by the need for some degree of similarity between targets and distractors to generate interference in the VSTM. In addition, this filter must embody a spatial dimension as changes across too large a spatial area abolish lag 1 sparing (Visser et al. 1999). This would suggest that the focus of the attentional filter is narrow both spatially and temporally. According to this account, when a switch occurs, T1 and T2 are not processed together: because of the switch requirement, a new filter needs to be set up which takes time, hence the decreased performance (Enns et al. 2001). If the second target is not allowed access to higher level processing, the representation is held up in the initial stage, which is more susceptible to masking interference and to degradation.

This filter must operate at an early stage within the visual system, as it needs to react quickly to rapid changes in attentional set and response planning. In addition, this mechanism is presumably intelligent, as its function relies not only on physical stimuli representations, because lag 1 sparing has been demonstrated with categorical changes within the stimulus set (Maki et al., 1999). Intelligent filtering, as proposed by Visser et al. (1999), assumes an interaction between exogenous and endogenous influences. According to this account, input filters are under the control of the prefrontal cortex and determine the level of processing afforded any given stimulus (Hommel, Kessler, Schmitz et al., 2006). Later filtering, however, is at least in part stimulus driven. That is, the nature of the stimulus determines the activation of a specific processing module, hence some level of exogenous control over filtering. This is reflected in the functional organisation of the brain with independent processors operating in parallel on stimuli passing input filters (Allport & Hsieh, 2001; Enns et al., 2001). It is important to note, however, that distinguishing between models that influence inputs as well as outputs to processing stages versus those that emphasise primarily processes that operate on the outputs is not straightforward.

1.4.2 Theoretical accounts of the visual AB

The AB research within the visual domain is extensive. From its conception, an important issue has been the extent to which the AB is due to either central processing limitations or modality-specific mechanisms Arnell & Jolicoeur, 1999; Chun & Potter 1995; Jolicoeur 1999; Shapiro et al., 1994; Visser et al., 1999). In the initial work due to Broadbent and Broadbent (1987), post-target intrusions made up a large proportion of errors made for the RSVP task. Post-target intrusions have been attributed to two mechanisms; an initial featural search activated by the physical properties of the stimuli, then the capture and post categorical processing of the stimuli (Broadbent & Broadbent, 1987; Lawrence, 1981). Raymond et al. (1992) expanded upon the previous work and investigated post-target intrusions through adjusting the similarity between T2 and the T2 +1 item. Increasing the similarity therefore strengthens an inhibitory process that suppressed the processing of T2. Initially this process of inhibition was described as an all-or-nothing process (Raymond et al. 1992) but the fact that T2 identification was typically attenuated rather than abolished led to the formulation of a theory attributing the AB to competition within the VSTM (Shapiro et al. 1994). A competition for resources model arguably better fits the exponential relationship between performance and T-D similarity than does an all-or-none account. Chun and Potter (1995), however, questioned the explanation that the AB results from competition within the VSTM, suggesting the locus of the AB effect was at a post perceptual stage. Chun and Potter's (1995) Two-Stage model suggests that T2 is held up once captured in a limited capacity store, whilst T1 is processed and elevated to a conscious representation in the VSTM. These different models and their implications are discussed below.

1.4.2.1 Attentional Suppression model: Raymond et al. (1992)

Raymond et al. (1992) proposed that the AB results from a capacity limitation in the attentional system. The fact that the visual AB is not a result of a perceptual processing bottleneck has already been discussed (see section 1.4.1.2). Raymond et al. suggested a similar mechanism for the AB to that proposed by Weichselgartner and Sperling (1987) whereby attention is allocated episodically. According to this account, each episode has a finite duration and items occurring within this episode are captured while items occurring outside this episode are missed. This all-or-nothing process was seen to be analogous to an eye-blink, hence the term Attentional Blink.

The model proposes two stages to target detection; the initial stage identifies the target as being different from the non-targets due to some featural aspect (e.g. a white target amongst black distractors) and is detected preattentively. During the initial stage, the +1 item is allowed entry to the system, which is attributed to the sluggish closing of the attentional gate (Weichselgartner and Sperling, 1987). During the second stage, attention is then focused initially on the attentional episode containing both the target and the + 1 item. Items that fall outside this episode remain in VSTM where they may be confused with other items or over-written while T1 and perhaps T1+1 are processed. Items that occur more than 300 ms after T1 are not held in VSTM and are processed in a later attentional episode (as stated previously by Duncan & Humphreys, 1989).

Lag 1 sparing is consistent with this theory; temporally adjacent items are encoded at the same time within the same attentional episode. The fact that the AB effect is abolished with the removal of the item from the +1 position is also consistent with this account, because of the lower demands on VSTM.

1.4.2.2 Retrieval Competition model: Shapiro et al (1994)

This model was a revision of the Attention Suppression model (Raymond et al., 1992), and was motivated in part by the fact that there is ample evidence that 'blinked' items do receive some kinds of information processing.

The Retrieval Competition model differs from the Attention Suppression model in relation to the locus of selection, assuming a late, rather than early, point of selection. The model proposes creation of an initial target template, which allows T1 entry to VSTM. T1 is captured along with the +1 item (in keeping with the notion of perceptual load from Lavie and colleagues, see earlier comments) probably due to its temporal proximity. Consequently, the post-target item is afforded a level of processing above that of the other non-target items, which as discussed earlier may relate to a residual increase in noradrenergic activation (Nieuwenhuis, et al, 2005, see section 1.4.2.6 for review). The rationale for the postulation of this higher weighting for the +1 item stems from Raymond et al.'s findings relating to the finding of post-target intrusions, suggesting interactions within the VSTM (Shapiro et al., 1994). According to the competition model, instead of the activation of an inhibitory mechanism, the interaction of the target and the +1 item create competition for retrieval from the VSTM. This model predicts that the competition will be less severe when the dissimilarity between the targets increases (e.g. Experiments 5A & 5B Shapiro et al., 1994). This model can account for all of the data that the suppression account explanations, but Shapiro et al. do note that this model does not explain the production of the AB deficit with the use of a random dot pattern as T1, and an 'X' as T2. They suggest that perhaps the dot patterns share similar featural aspects with the letters, in both colour (use of black targets and distractors) and pattern.

1.4.2.3 Two-stage model: Chun and Potter (1995)

The Two-Stage model (Chun & Potter, 1995) expands upon the initial findings of Broadbent and Broadbent (1987) in which a two filter system (detect-then-identify) was believed to be operating. The target is detected by the first, capacity free stage, which then activates a second, capacity limited system that consolidates featural identity and allows conscious access to the target representation. The first stage, rapid detection, scans all incoming items for relevance to a predetermined target template, based on featural similarities such as category, colour or even the letter case of the item. This representation is short lived and fragile, requiring rapid action (consolidation). Items at this stage are subject to 'rapid forgetting' (Chun & Potter, 1995, p.122) due to the constant intake of subsequent items from the RSVP. The build up of items can lead to competition and subsequent decay, if the items are not consolidated. The second, capacity-limited processing stage is thought to strengthen the representation it receives based on detection. This process does not begin with the presentation of the stimulus, but with transfer from the initial stage. It has been hypothesised that this transfer has a temporal dimension similar to the timing of a visual attentional episode (Weichselgartner & Sperling, 1987), whereby the capture of the initial item results in the capture of the subsequent item at a rate of around 10 items/s.

The activation of this initial system cannot be halted once initiated, so has to carry out a prescribed action with a fixed temporal cost (attentional dwell-time, Duncan, Ward & Shapiro, 1994; Ward, Duncan & Shapiro, 1996). Therefore, decreasing the SOA (increasing the number of items/s) between targets increases the time the target item has to wait in a very limited capacity store before it is processed. Representations decay during this period and this is the critical factor for explaining performance in attentional blink tasks. Only when the processing of the initial target is completed is the second target allowed access and is processed without interference. This is reflected in an increase in performance after approximately 300 ms. The process of elevating the representation to a conscious level is not a fixed variable, as performance gradually increases rather than being a simple on/off function. This gradual increase in performance may be responsible for the variation across the task as well as the population.

Chun and Potter (1995) investigated parameters that influence the magnitude of the AB. In one experiment, participants had to detect and identify alphanumeric targets at varying SOAs (100 ms). Participants were to make judgments on three targets with varying SOAs. ABs were demonstrated for T1 and T2, and T2 and T3, showing the deficit can occur with any target irrespective of how many there are in the presentation. Initially Chun and Potter manipulated categorical differences between targets and distractors, investigating access to the initial stage of their model, in order to examine the possible influence of preattentive biases. A bias would allow a more rapid selection to the initial stage for some contents, thereby reducing workload in the second stage reducing attentional suppression. In addition, reducing task load by implementing the same task for both targets (no switch between tasks for T1 and T2) demonstrated 'typical' AB behaviour.

The proposed model describes a more dynamic nature to attention as opposed to Weichselgartner and Sperling's (1987) sustained attention proposal whereby the deficit in detection of T1 occurs with every item that is afforded enough time between the activation of the process (Chun & Potter, 1995). Results supported a two-stage model whereby the detection of each target highlighted processing 'bottlenecks'. The removal of the T1 post-target item and its replacement with a blank space (Raymond et al. 1992), dramatically improves T2 performance thus eliminating the AB. This suggests that the degree of difficulty of the T1 task, either in terms of temporal (e.g. +1 space is blank) or featural similarity, determines T2 performance.

Raymond et al. suggested the AB would be modulated by target-distractor similarity due to interference caused by featural similarity between T1 and T2. However, it is not simply a question of similarity between visual features but of category, or stimulus set, as digit targets created a larger AB compared to keyboard symbol targets (keyboard symbols matched for featural likeness). For example, with the use of letter targets, symbol distractors did not produce an AB; however, a pronounced AB was produced with digit distractors (Chun & Potter, 1995). Additionally, inversion errors –the increased likelihood of incorrectly identifying T2 and T1 and vice versa were almost three times as likely to occur with digit distractors.

One explanation for this stems from the observation that if digits were more recognisable, they would engage more resources therefore creating a larger bottleneck effect. This suggests again that higher frequency items create a larger masking effect by increasing interference and thus slowing the pathway to higher conscious functions. This lends more evidence to the idea that visual templates are created for the targets are too different to the patterns of the symbols, and therefore are considered irrelevant. Digits engage the templates but due to a degree of mismatch, an increase in processing resources is required to try to fit the items.

This model shares some similarities with the previous models of the AB in that T1 and the +1 item are processed together, and that the degree of interference (the

AB) is proportional to the degree of similarity, with regard to both global (categorical) and featural similarity. The Attentional Suppression model (Raymond et al. 1992) differs from the Two-Stage model because of the concept of a discrete attentional gate: the 'gate' is either open or closed, whereby no transfer of information can occur when the gate is closed, however, some must pass through as performance is rarely at floor for blinked items.

1.4.2.4 Central Interference Theory: Jolicoeur (1999)

The Central Interference Theory proposes a different explanation for the AB, mainly due to the fact the model was developed using data outside of the visual modality, in particular cross-modal AB studies (see section 1.6.1 for discussion). One question arising from the previous models is the locus of the processing operations that are responsible for the AB: is the AB purely a visual phenomenon and due to domain-specific specific visual processes, or is the AB, in whole or in part, due to domain-general (central, or 'amodal') processing operations). Both the Two-Stage (Chun & Potter, 1995) and Retrieval Competition models (Shapiro, et al 1994) explain and predict behaviour for visual presentations only. The Central Interference model suggests that the deficit in performance during the AB is due to interference at an amodal juncture that ties up central resources.

The model is a more general version of that proposed by Chun and Potter (1995); their model explains a very specific action defining the processes of the AB with reference to the VSTM. The AB occurs due to temporary postponement of stimulus processing, as previous items are being processed. Jolicoeur's model identifies a special process for the encoding of information into a general STM. This process is short-term consolidation (STC). This model differs from that of the two-stage model as processes other than memory encoding (e.g. response selection, transfer of control demands such as bottom-up perceptual actions) are able to interfere with the STC process. The central interference model assumes the second task (identification of T2) requires central processing in order for T2 to be encoded into the STM. STC of T2 cannot occur whilst processing of T1 is occurring. This bottleneck occurs as response selection is initiated for the first item. Secondly, the assumption is made that cognitive functions that do not require central processing are carried out irrespective of other non-centralised operations.

1.4.2.5 A Neurocomputational model (Nieuwenhuis, Gilzenrat, Holmes & Cohen, 2005)

Nieuwenhuis et al (2005) proposed a neurobiological mechanism for the visual AB effect. This model expanded upon previous research implicating the neuromodulatory brainstem nucleus locus coeruleus (LC) in the regulation of cognitive performance. An increase in activity within the LC during the processing of motivationally relevant stimuli leads to increased production of norepinephrine (NE) (Nieuwenhuis et al., 2005). Local NE release within the LC has an inhibitory effect upon the processing of a response to a stimulus, producing a period in which LC-NE mediated information processing is largely unavailable. This period of reduced activity coincides with the temporal parameters of the AB. Evidence from nonhuman primate studies in simple signal detection tasks (detection of a rare target from within a stream of distractors) has shown LC firing rate peaking between 100 and 200 ms post-target (Nieuwenhuis, et al 2005). These findings suggest that phasic bursts in the LC-NE system play an important role in the processing of task relevant stimuli, and importantly these bursts occur within a short period of the eliciting stimulus and are followed by a period of functional refractoriness. This period of noradrenergic autoinhibition of the LC leads to the temporary unavailability of the NE-mediated action. According to this model, the result in AB tasks is the processing deficit seen for T2.

The model comprises a behavioural network consisting of three layers; input, decision and detection (see Fig. 1.6). There are "feed-forward excitatory connections between layers and mutual inhibitory connections between units and decisions and layers stimulating competition between alternative representations" (Nieuwenhuis et al., 2005, pp 294). The input layer comprises three input units for each stimulus type (i.e. T1, T2 and distractor), processed within one single dedicated pathway (three types of input rather than each distractor being represented separately). Stimulus detection is stimulated by the activation of a particular unit, which activates the decision units by means of the LC elevating the representation to the detection level (see Fig 1.6). As participants are not required to identify the distractors there are no detection units for distractor items.

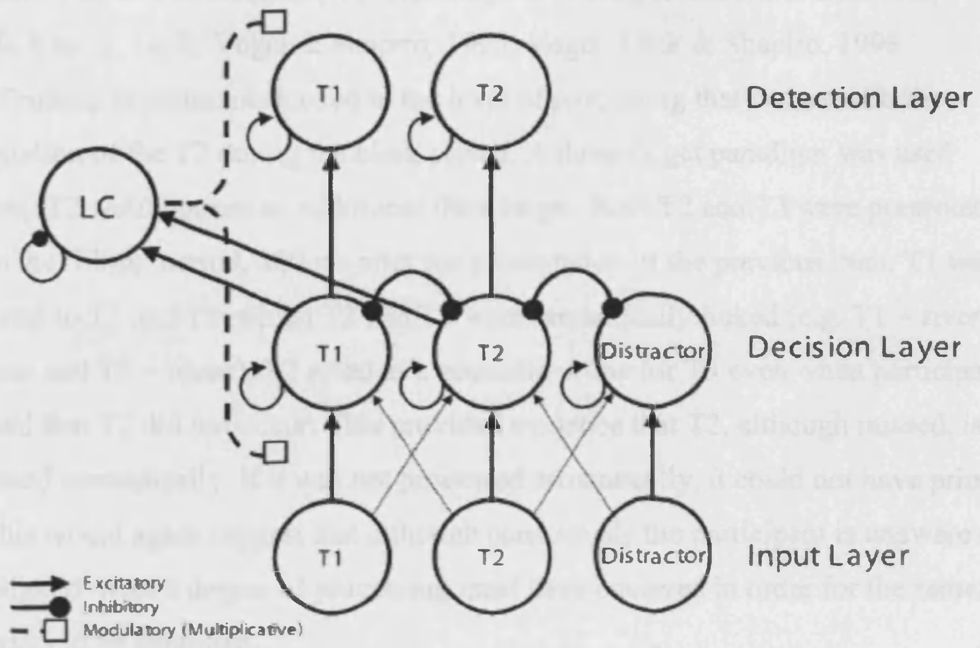

Figure 1.3: Architecture of the computational model proposed by Nieuwenhuis et al (2005) depicting the flow of activity from the input layer, through the decision layer to the detection layer under the influence of the LC.

The model incorporates lag 1 sparing by assuming that the noradrenergic boost from the LC phasic response to one stimulus can influence the processing of another stimulus during a critical time window. With contiguous target presentation, T2 will escape the detrimental LC refractoriness. Nieuwenhuis et al. do stress however, that with their present data they are unable to determine the width of this window, only that it is there. For studies in which lag 1 sparing is not demonstrated, as noted by Visser et al., (1999), an additional factor (i.e. switch in location, task demands) is assumed to be responsible, and this overrides the benefit of residual NE production.

1.4.2.6 Evidence for models

Both the Two-stage model and the Central interference model suggest that the AB deficit is due to a delay of postperceptual processing for the second target. This suggests that during the blink period the second target is captured but is not allowed subsequent consolidation into a more stable representation available for report. There is ample evidence, however, that items that do not reach the conscious awareness sufficient for accurate report receive considerable post-perceptual processing

(Shapiro, Cadwell & Sorenson, 1997A; Shapiro, Driver, Hillstrom & Sorenson, 1997B, Exp. 2; Luck, Vogel & Shapiro, 1996; Vogel, Luck & Shapiro, 1998

Priming experiments looked at the level of processing that occurs with the presentation of the T2 during the blink period. A three-target paradigm was used whereby T2 would prime an additional third target. Both T2 and T3 were presented within the 'blink' period, 300 ms after the presentation of the previous item. T1 was unrelated to T2 and T3, whilst T2 and T3 were semantically linked (e.g. T1 = river T2 = doctor and T3 = nurse). T2 acted as a semantic prime for T3 even when participants reported that T2 did not occur. This provided evidence that T2, although missed, is processed semantically. If it was not processed semantically, it could not have primed T3. This would again suggest that although consciously the participant is unaware of the 'blinked' item a degree of processing must have occurred in order for the semantic properties to be exhibited.

ERPs have been utilised in order to examine the locus of the AB deficit more precisely. ERPs measure brain activity from the surface of the scalp by recording small electrical polarity differences at various locations for approximately 1-2 seconds after events of interest (e.g. the presentation of a specific stimulus). In the case of the AB, this would be T2. The activity occurring after this event is recorded many times and the signal produced is then averaged across trials. This is done because the brain constantly produces activity irrelevant to the stimulus. This background activity is considered random, so therefore an average would remove the random factors leaving a clean representation of the activity specific to the stimulus.

Luck et al. (1996) and Vogel et al. (1998) measured two electrical potentials; the N400, which is sensitive to semantic processing, and the P300, a positive deflection believed to represent contextual updating in working memory that occurs after identification of a target stimulus. By using a word item presented in an RSVP, they used a T2 that could be semantically similar or dissimilar to T1. The N400 behaved in a way that was consistent with the view that T2, even when missed, was processed semantically, mirroring the behavioural results discussed above (Luck et al. 1996).

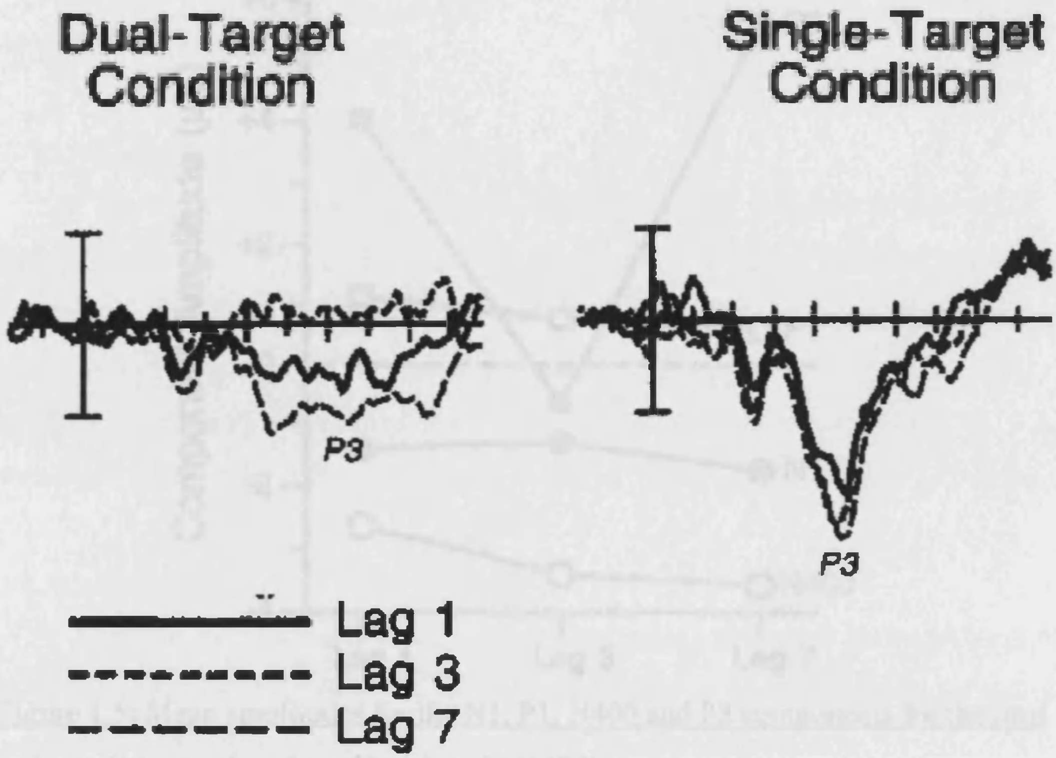

Figure 1.4: Grand average event related potential difference when subtracting trials with the frequent T2 from trials with infrequent T2 recorded at the central midline electrode point: taken from Vogel et al., (1998)

In addition, missed items did not elicit a P300, which locates the AB processing deficit at the stage of working memory. Figure 1.7 shows the reduction of a positive deflection around 300-400 ms post T2 when presented at lag 3 for the dual task condition. It is also notable that early visual evoked potentials, that signal how well stimuli are perceived, did not differentiate between missed and correctly identified items. The selective suppression of the P3 component only (see Figure 1.8) locate the visual AB at a post-perceptual processing stage, indicate that missed items are still afforded semantic processing, and generally support two-stage accounts of the AB.

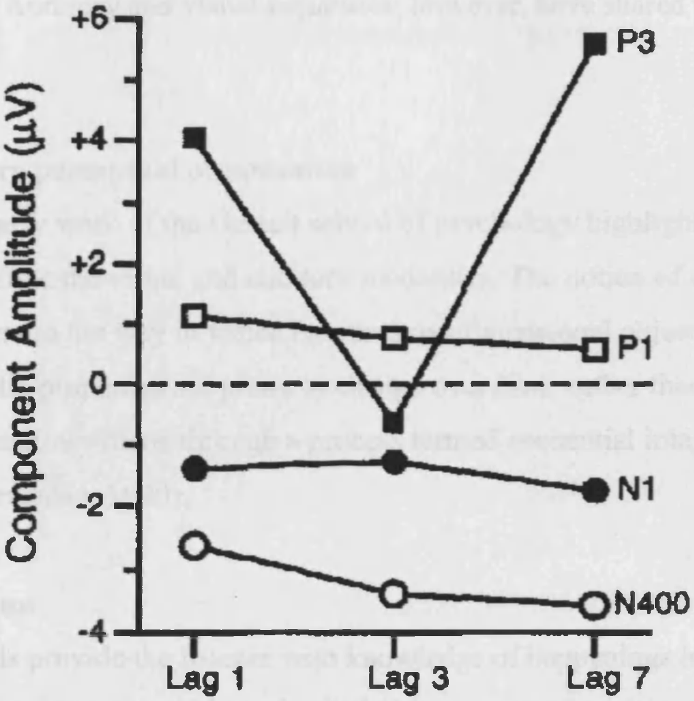

Figure 1.5: Mean amplitudes for the N1, P1, N400 and P3 components for the dual task conditions: taken from Vogel et al., (1998)

1.5 The Auditory Attentional Blink

The focus in this thesis now turns to the AAB, and a consideration of important factors that may be relevant to this phenomenon as well as similarities and possible differences between the AAB and the visual AB (VAB) discussed above. One obvious aspect concerning the auditory attentional blink (AAB) is the fact that one is measuring a different sensory modality. Simple differences between vision and audition concern the sensory array, the fovea and the auditory canal. The fovea is housed in a manoeuvrable organ that detects changes across space and can orient itself. Human pinnae are manoeuvrable however, only to a very small extent, so the auditory system needs to segregate different items within the flow of information. One example of this difference comes from the area of RB (repetition blindness), whereby RB effects in the visual domain are not evident in the auditory domain when similar presentation rates are used (Kanwisher & Potter, 1989). Although it seems trivial to state, it is none the less important that sounds generally behave differently to visual representations in that they characterise themselves via changes over time rather than across space. Auditory and visual *sequences*, however, have shared temporal similarities.

1.5.1 Auditory perceptual organisation

The early work of the Gestalt school of psychology highlighted perceptual factors that affect the visual and auditory modalities. The notion of visual perceptual grouping refers to the way in which two or three-dimensional objects behave across space. Acoustic properties are prone to change over time, rather than space. The grouping of auditory items through a process termed sequential integration, or streaming (Bregman, 1990).

1.5.1.1 Streams

Sounds provide the listener with knowledge of happenings in the world around them. Sounds tend to occur when physical objects are set in motion; these sounds are carried through some elastic medium (usually air) and transmitted to the ear, which converts these motions to coded nerve impulses. Many events may occur simultaneously, however sounds created from one object tend to share acoustic properties (Bregman, 1993). The acoustic and temporal properties of sound allow the listener to segregate sounds into objects. This segregation of acoustic events into different perceptual objects allows the formation of streams.

Perceptual groups are strongly determined by Gestalt configuration properties such as common fate and exclusive allocation. Common fate relates to the changing of these events over time, as unrelated events rarely start and stop at the same time (Bregman, 1993). As temporal changes allow description of auditory events, this particular property is very valuable. In addition, acoustic events derived from the same source seldom vary, with any change being very gradual (Bregman, 1993). Bregman (1990) adds to this the Gestalt idea of exclusive allocation, citing as an example the visual illusion of the ambiguous vase/faces drawing (Figure 1.9). The image has three horizontal symmetrically defined areas. The illusion forces the viewer to perceive either a vase or a face exclusively via the allocation of shape to one representation whilst inhibiting the other. The viewer can switch between precepts that exist exclusively and cannot co-exist.

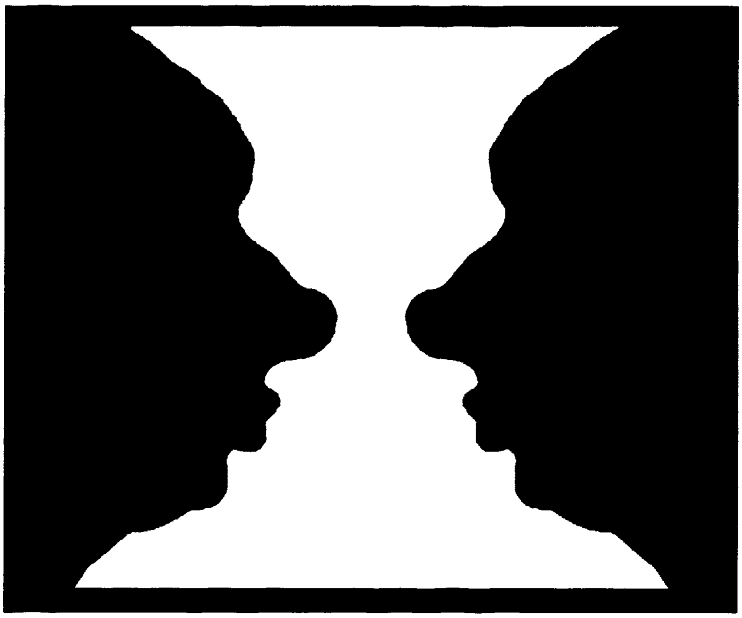

Figure 1.6: Example of Edgar Rubin's ambiguous face/vase drawing

An auditory analogue of this illusion was devised by Bregman and Rudnicky (1975) using a pattern of pure tones. When two target tones with distinct frequencies were presented in isolation, a judgement as to the order in which they were presented was very easy. With the introduction of two tones flanking the target items (of different frequency), the task became much harder. However, with the inclusion of more tones at the same pitch as the flankers (termed 'captors') the task became easy again. The explanation for this is that the captors bind the flankers into a distinct stream that becomes exclusively allocated to something other than the target stream.

1.5.1.2 Perceptual organisation and the AAB

The perceptual organisation of sounds is a key concept that requires attention in any experiment involving auditory materials. However, in previous AAB studies, these factors have received very little consideration, or at least an explanation for the types of stimuli used is rarely given. As noted previously, the acoustic nature of the stimuli will determine the strength of the grouping potential. The AAB utilises an RAP procedure, rapidly presenting targets and distractors to the listener. Due to the rapid rate of presentation and the separation of the items, organisational factors will be of great influence. Due to acoustic similarities, the target items may either group with one another to form a more coherent unit with the distractor items (e.g. Bregman & Rudnicky, 1975).

Studies investigating the AAB can be broadly divided into two groups; those that promote streaming, by using repeated and cycling distractor tokens (Duncan et al. 1997; Tremblay et al. 2005), and those in which perceptual organisation is not a consideration (i.e. items are presented randomly). The latter use single alphanumeric (Arnell & Jolicoeur 1999; Arnell & Larson 2002; Potter et al. 1998) or pure tone (Mondor, 1998) distractor tokens, in such a way as to be analogous to the visual paradigm. The presentation of random distractors, although in the same voice, may not create streams due to a lack of predictability.

The most compelling evidence for the AAB used repeated tokens ('guh') as distractors (Duncan et al. 1997; Tremblay et al., 2005). One explanation for this is that the repetition of a single item over a short time will result in the perception of one stream due to acoustic similarity of the acoustic properties of each item. As found by Bregman and Rudnicky (1975), the introduction of a novel item, a target, is easily detected, outside the established stream. This is because the difference between distractor and target is acoustically significant, thus allowing a greater distinction between the to-be-ignored and the to-be-identified item.

This theory of perceptual organisation has implications for the whole of the auditory presentation when distractor sequences are ordered. For the VAB, very little consideration is given to items occurring before T1 (pre-T1 items)[1], as the role of the +1 item as a mask is reflected in all theoretical explanation of the VAB. However, perception of auditory items is highly dependent upon exposure to the *previous sequence* of previous items. Auditory streaming exploits the commonalities of auditory information within the environment, and these commonalities are based on numerous previous exposures, not simply the items that fall temporally adjacent to critical task stimuli. What this means is that, for segregation into streams, each auditory event is processed in relation to the preceding sequence and the percept is determined in part by the stream. Therefore, the nature of the exposure to auditory pre-T1 items may well define the nature of the +1 item, thereby modulating its masking potential. These factors are not considered as critical with respect to perceptual organisation in the visual domain.

Tremblay et al. (2005) demonstrated this modulation with the presentation of repeated 'guh' distractors and cycling changing 'guh', 'gih' and 'gah' distractors. A larger AAB was demonstrated with the changing distractors than with the repeated.

[1] All VAB studies manipulate the number of pre-T1 items however no reporting of differences based upon this manipulation are reported

Increasing the number of potential streams from three (one distractor and two targets, the repeated distractor sequence) to five (three distractors and two targets, the changing distractor sequence) likely increased perceptual competition thus increasing masking potential. This may be reflected in a restriction of processing allocation in a similar way to masking in the visual domain.

1.6 A review of AB studies across and within different modalities

The proliferation of visual AB studies (Chun & Potter, 1995; Enns, Visser, Kawahara & Di Lollo, 2001; Giesbrecht & Di Lollo, 1999 Raymond et al., 1992; Shapiro et al., 1994) prompted investigators to examine whether similar attentional deficits occurred if one or both targets were presented in another modality (Arnell & Jolicoeur, 1997). The initial question driving AB experimentation in other modalities was whether similar temporal constraints on information processing existed outside of the visual modality (Arnell, 2001). If the AB is modality specific then no intra-modal interactions would be elicited, but an interaction would suggest the AB may result at least in part from a central 'bottleneck' (Arnell & Jolicoeur, 1997; Jolicoeur, 1999). There are now a number of studies in which variants of the RSVP procedure have been employed in order to examine attentional dynamics across visual and auditory modalities (Arnell & Jolicoeur 1995, 1999; Arnell & Larson 2002; , Martens & Ward, 1997, Experiment 1; Potter, Chun, Banks & Muckenhoupt 1998; Shulman & Hsieh, 1995), vision and touch (Soto-Faraco, Spence, Fairbank, Kingstone, Hillstrom & Shapiro, 2002) and within the auditory modality only (Duncan, Martens & Ward, 1997, Experiment 2; Mondor, 1997; Tremblay, et al., 2005).

1.6.1 Visual-auditory cross-modal AB studies

Potter, Chun, Banks and Muckenhoupt (1998) presented participants with a stream of alphanumeric items in either the visual or auditory modality. Participants were separated into two groups: those who have to identify two targets (experimental group) and those who had to identify just one (control group). Visual items were presented at a rate of 8.33 item/s whilst auditory items were presented at 7.41 item/s. The task was to detect letter targets among digit distractors.

A 'typical' AB effect was found when both items were presented visually; however, with items presented in the auditory modality performance did not vary as a function of T1-T2 SOA. Overall, performance was lower for the auditory modality, suggesting participants found the auditory task more difficult. This differential effect across modalities was replicated with matched presentation rates of 7.41 items/s.

Cross modal effects were also investigated by presenting T1 and T2 in different modalities within the same sequence. Using the same presentation rates demonstrated no T1-T2 SOA interactions across modalities, although performance was very high, c. 90%. Potter et al. (1998) concluded that the AB exclusively occurs within the visual modality owing to the unique susceptibility of items within the VSTM, and the relatively short lifespan of items within iconic memory (see section 1.5.2 for further discussion).

Shulman and Hsieh (1995) adopted a similar procedure to that of Potter et al (1995, 1998) to examine modality interactions. T1 was differentiated from the distractors by either being of a higher luminescence or pitch dependent upon modality. The task for T2 was to detect a predetermined letter from the post T1 stream. A slightly faster presentation rate of 7.95 items/s was used compared to Potter et al (1995, 1998). Reliable ABs were found in both within-modality conditions and the crossed auditory condition (an auditory T1 followed by a visual T2). Performance for the within auditory condition was greatly reduced (difference between experimental and control conditions was at a maximum of 10%) compared to the within visual and auditory crossed conditions (largest difference between experimental and control condition was approximately 20%). No evidence for the AB was obtained in the visual-auditory condition.

This pattern of results led to the conclusion that the same cross-modal interactions may elicit similar AB behaviour. However, due to the lack of a visual-auditory AB and the implementation of a (pitch/luminand) switch between targets, the data may be describing the reallocation cost inherent in the switch rather than competition for the same resources (Potter et al., 1998).

The seminal work of Duncan, Martens and Ward (1997) demonstrated different results using a very different procedure. Their paradigm differed in two main ways. Firstly, the targets were presented in two offset streams with items overlapping (see Figures 1.10 & 1.11). Each item was presented for 150 ms with an ISI of 100 ms. The second stream started 125 ms after the initiation of the first stream. The targets were consonant-vowel-consonant (c.v.c) words ('cod' or 'cot' and 'nab' or 'nap') with the repeated phonemic syllable 'guh' for the auditory sequence and 'xxx' for the visual sequence as distractors. Visual items were presented in two spatial locations (left and right of screen) with targets appearing at one location (see Fig. 1.4); whereas the auditory targets were of either a high or a low pitch, with distractors being of an intervening pitch (see Fig. 1.5). The target presentation order was fixed (e.g. if T1 = 'cod' or 'cot', then T2 = 'nab' or 'nap'). Secondly, each stream had a presentation rate of 4 items/s (250 ms SOA). The participant had to either identify one target (e.g. only the auditory target) in the control/focused condition or identify both targets in the experimental/divided condition.

Reliable ABs were demonstrated with the presentation of both targets within the same modality (Experiment 1) but no T1-T2 SOA cross modal interaction was shown (Experiment 2). Duncan et al. (1997) concluded that modality specific attentional restrictions do occur, however these are independent of each other and do not impede central processing.

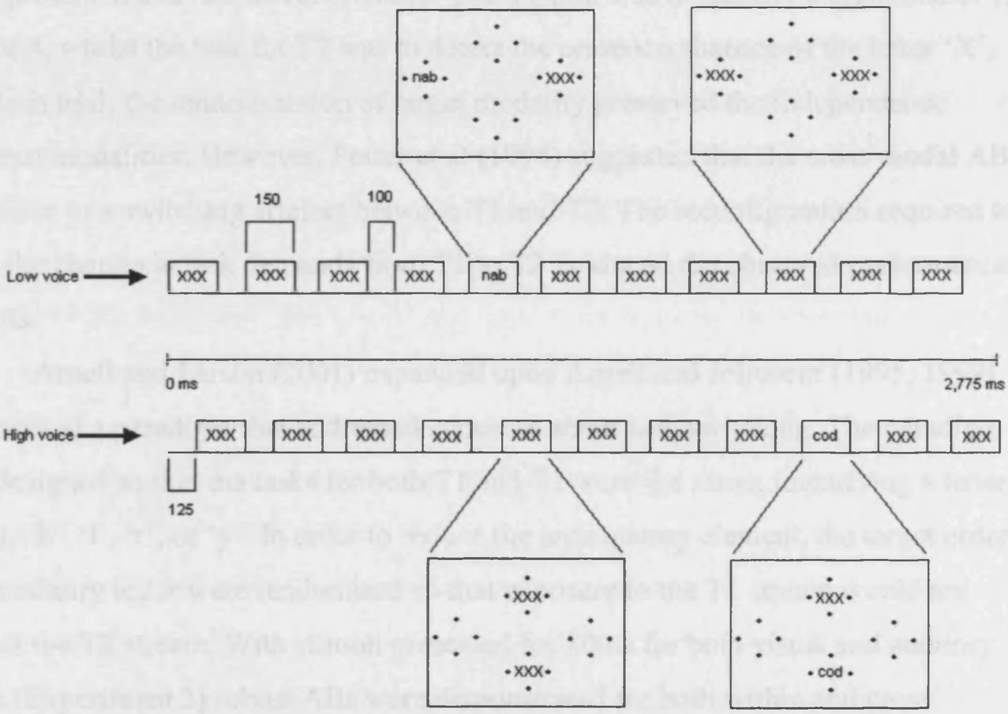

Figure 1.7: Graphic representation of dual stream visual target and distractor presentation from Duncan et al. (1997)

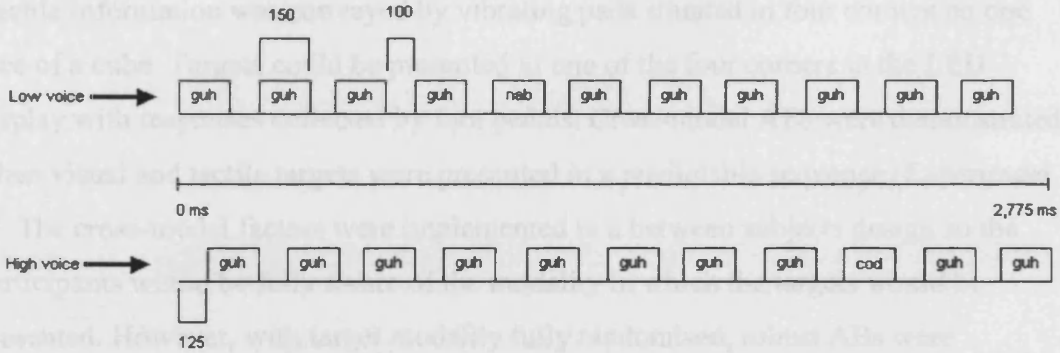

Figure 1.8: Graphic representation of dual stream auditory target and distractor presentation from Duncan et al. (1997)

In contrast, Arnell and Jolicoeur (1995, 1999) were able to demonstrate ABs in all within and cross modality conditions. Participants were exposed to concurrent letter RSVP and RAP streams with simultaneous onsets. Items within the sequence were presented at a rate of 10.7 items/s. The T1 task was to identify a digit, one of 1, 2, 3 or 4, whilst the task for T2 was to detect the presence/absence of the letter 'X'. For each trial, the randomisation of target modality preserved the independence between modalities. However, Potter et al (1998) suggested that the cross modal ABs arose due to a switching artefact between T1 and T2. The reconfiguration required to meet the change in task demands from T1 to T2 produced the observed performance deficits.

Arnell and Larson (2001) expanded upon Arnell and Jolicoeur (1995, 1999) and created a paradigm that addressed concerns about task switching. The paradigm was designed so that the tasks for both T1 and T2 were the same; identifying a letter target, 'k', 'l', 'r', or 'y'. In order to reduce the anticipatory element, the target order and modality order were randomised so that exposure to the T1 stream would not predict the T2 stream. With stimuli presented for 80ms for both visual and auditory items (Experiment 2) robust ABs were demonstrated for both within and cross modality conditions.

1.6.2 Visual-Tactile Cross-modal study

Soto-Faraco, Spence, Fairbank, Kingstone, Hillstrom and Shapiro (2002) investigated the existence of cross-modal ABs between vision and touch. Participants were presented with a light emitting diode (LED) configuration in a 3 x 3 display. Tactile information was conveyed by vibrating pads situated in four corners on one face of a cube. Targets could be presented in one of the four corners in the LED display with responses collected by foot pedals. Cross-modal ABs were demonstrated when visual and tactile targets were presented in a predictable sequence (Experiment 1). The cross-modal factors were implemented in a between subjects design so the participants would be fully aware of the modality in which the targets would be presented. However, with target modality fully randomised, robust ABs were demonstrated for both visual and tactile modalities.

1.6.3 Auditory within-modality studies

Tremblay, Vachon and Jones (2005, Experiment 2) employed a variant of Duncan et al.'s (1997) paradigm. The same targets and distractor were used, but the method of presentation differed. Firstly, both targets and distractors were presented in the same stream, at the same pitch (see Figure 1.6). As with Duncan et al.'s (1997) paradigm, the order in which the targets were presented was fixed. Each item was presented for 150 ms, with no ISI. Tremblay et al. added one important experimental difference relating to the context in which the target items were presented. There were three contexts: firstly, the targets were presented with no distractors; secondly, (as with Duncan et al.) the targets were presented within a distractor stream that consisted of the repeated syllable 'guh' (Figure 1.12), and finally the distractor stream contained three phonemic syllables, 'guh', 'gih' and 'gah' (this sequence was repeated and in a fixed order, see Figure 1.13). The two targets were separated by four SOAs: 150, 300, 600 and 1350 ms, described here and elsewhere as lags 1, 2, 4 and 9.

Reliable ABs were demonstrated when target items were presented with distractor items. Performance, when the targets were presented within a context is dramatically effected at lag 2 reflected by the demonstration of lag 1 sparing. A larger AB was revealed for the repeated distractor condition.

The modulation in distractor type influenced the context, demonstrating the effect of perceptual organisation; that is, the way in which the perceptual system groups the raw elements of sounds (Bregman 1993; discussed in greater depth in section 1.5.3). In addition, lag 1 sparing was demonstrated, in contrast to the findings of Duncan et al (1997) (see section 1.6.1 for further discussion).

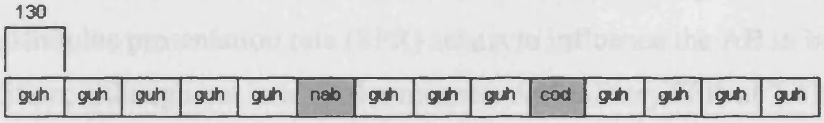

Figure 1.9: Graphic representation of single stream repeated distractor auditory presentation

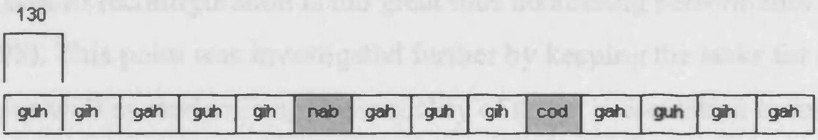

Figure 1.10: Graphic representation of single stream changing distractor auditory presentation

Mondor (1997) investigated transient processing deficits with auditory targets. The task can be considered an auditory analogue of the RSVP technique used extensively within the visual modality (Raymond et al., 1992, Chun & Potter, 1995). Targets were presented within a stream of pure tone distractors. T1 was differentiated from the distractors, as it was higher in pitch, whilst T2 was a complex sound comprising five pure tones. Participants were required to make present/absent judgments for both T1 and T2 for every trial. Each item in the sequence was 30ms in duration with a 60ms ISI. A reliable AB was shown (Experiment 1) with performance demonstrating a linear asymptotic T2-SOA interaction without demonstrating lag 1 sparing.

1.6.4 Summary of non-visual within modality experiments

The range in tasks and task parameters employed to investigate the existence of an AB outside of the visual modality may contribute in part to the range of findings reviewed above. The results range from a complete absence of an AB in audition but not vision (Potter et al. 1995, 1998) to demonstrating ABs within and across visual and auditory modalities (Jolicoeur & Arnell, 1995, 1999) as well as touch (Soto-Faraco et al. 2002). The methodologies differed in both the stimulus presentation rate

(Arnell & Jolicoeur, 1999; Potter et al., 1998) and the tasks required for T1 and T2 (Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Potter et al., 1998). As noted by Arnell (2001), stimulus presentation rate (SPR) seems to influence the AB in both vision and audition, although not in a similar manner. An auditory SPR of 7.41 items/s demonstrated no T1-T2 SOA interaction, however increasing this rate to 8.33 items/s reverses this trend (Arnell & Jolicoeur 1999).

The cross-modal ABs demonstrated by Arnell & Jolicoeur (1995, 1999) may have been artefactual, arising from imposing a switch in attentional set and task demands of T1 and T2 (Potter et al., 1998). This switch imposed most demands at short SOAs: the cost of reconfiguration is too great thus decreasing performance (Potter et al., 1998). This point was investigated further by keeping the tasks for both targets the same, as well as randomising the modality of target presentation to reduce any anticipatory factors (Arnell & Larson, 2002). In addition, lag 1 sparing was only demonstrated, as with the VAB, when no switch was imposed across targets and with an ordered context.

1.7 Scope of the current empirical investigation

The relative dearth of empirical evidence concerning the AAB affords a window of opportunity. The elucidation of a detailed understanding of the visual attentional pathways allows a firm bed for comparisons to the auditory modality. The work already carried out on the AAB has also generated a range of questions relating specifically to the auditory paradigm. Questions concerning the locus of the AB effect within the auditory modality include whether the AAB performance decrement is attributed to similar processes to those described for the visual modality. Masking of the targets has been shown to be necessary for both the visual (e.g. Visser, et al., 1997) and auditory (Tremblay et al., 2005) AB. However, the nature of auditory information and events differ qualitatively allowing the manipulation of masking potential through the auditory scene (Bregman, 1990) by modulating the similarity and order within the distractors.

Conventionally, AB has been described as a breakdown in a process related to the transfer of events from a sensory or perceptual encoding stage into short-term storage. The serial nature of the process creates a potential for interference either from confusion in a short-term memory overcrowded with stimuli (e.g., Retrieval competition theory, Shapiro et al., 1994) or rapid forgetting due to a delay in T2 consolidation before the target is fully processed (e.g., Chun & Potter, 1995). There is some evidence suggesting that this broad framework may also apply in the case of the AAB. From a neurological perspective, the intraparietal sulcus (IPS) has been implicated in both the VAB (Marois, Chun & Gore, 2000) and auditory perceptual organisation (Cusack, 2005), thereby suggesting a possible link between the attentional processing occurring in both auditory and visual AB. In addition, the ease of target detection in an auditory scene can be moderated by the degree of similarity between targets and distractors (Bregman & Rudnicky, 1978), which is also an important feature of the boundary conditions for the VAB.

Controversy surrounds the phenomenon of lag 1 sparing within the auditory domain. Lag 1 sparing, believed to represent the consequence of T2 being presented directly after T1 without a task-switch (Visser et al., 1999), has only been reliably demonstrated in one AAB study (Tremblay et al., 2005). Additionally, lag 1 sparing was only demonstrated when the targets were presented within a structured context (Tremblay et al., 2005, Exps. 2 & 3) rather than with just targets and a proceeding mask (Tremblay et al., 2005, Exp. 1). Does a structured context change the perception of the targets allowing them to be perceived as the same event hence, in relation to the visual AB, being captured in the same attentional episode (Weichselgartner & Sperling, 1987)? Moreover, does lag 1 sparing survive certain switches between targets e.g. attentional or semantic set? The present thesis will attempt to answer these questions and discuss their relationship to the currently articulated explanations for the visual AB.

This research could potentially be of interest in applied psychological domains. The relationship between deficits in the visual AB and neglect (Husain, Shapiro, Martin & Kennard , 1997), as well as dysphoric mood (Rokke, Arnell, Koch & Andrews, 2002) and attention deficit hyperactivity disorder (Li, Chen, Lin & Yang, 2005) suggest that at least in principle there is some utility in developing measures of the AB as a diagnostic tool. Whether this is also true with respect to assessments of the AAB remains an open question. Somewhat tangentially, the auditory AB may elucidate the role of attention involved in auditory illusions, for example, the Glissando illusion (Deutsch, 1995). Perhaps more importantly, questions concerning the rapid integration of auditory and visual information have relevance to the designs of interfaces and environments, such as cockpits, where multiple sources of competing information need to be assimilated rapidly, and where some sources need to be prioritised.

Chapter 2

General methods

The purpose of this chapter is to highlight the procedures common to all of the empirical series. Any deviation from the procedures described here will be noted in the methods sections for the individual experiments.

2.1 Participants

All participants were recruited from Cardiff University (method for reimbursement for participation will be noted in each experiment) and reported normal or corrected to normal eyesight and hearing. Gender and age range of the participants will be noted in individual experiments. Informed consent was obtained before participation and the rights of the participants were protected. In most cases, a certain number of participants' data was excluded from the analysis due to very high levels of performance: the number of participants is stated in the relevant chapter sections. Data was excluded if performance was at ceiling, which was deemed to have occurred when the accuracy of judgments in every condition at every SOA exceeded 92%.

2.2 Materials

A male voice was used for all targets and distractors and was recorded digitally. Care was taken for the sample provider to produce vowels at an even pitch (using a pure reference tone at 103 Hz). All sounds were recorded at a sample rate of 44,100 Hz with 16-bit resolution and compressed to equal lengths, using Sonic Foundry's Sound Forge 5. All stimulus sequences were created in Sonic Foundry's Sound Forge 5. Stimuli for Experiments 10A, 10B & 11 were created from digital vocal recordings of a male voice captured via an Apple microphone and a Power Macintosh AV computer (these stimuli were kindly provided by Karen Arnell). The speech was sampled using 16-bit resolution at a sampling rate of 47 kHz, with

SoundEdit 16 software. All sounds were presented via Sennheiser HD250 liner II headphones at approximately 65dB. Experiments were controlled using Cedrus Superlab Version 2.0. Participants responded by pressing allocated keys upon a standard keyboard. Random sequences used for generating stimulus sequences were generated by using a random number generator (www.random.org).

2.3 Procedure

Each trial comprised a rapid auditory presentation (RAP) sequence in which there were always two targets. There were two attention conditions which every participant experienced, the control condition in which a response was required for the second target only, and the experimental condition where two targets necessitated a response (except for experiments 9A, 9B and 10 which comprised one condition only). The order of the presentation of the questions referring to the targets was always the same. Each participant received a practice session consisting of nine experimental sequence trials in which a response for only the second target was required. This, however, was not the case for experiments 8A & 8B, which were designed in order to investigate the effect of practice (See Chapter 4), nor for Experiments 9, 10A and 10B in which 12 practice trials were employed. A level of >= 75% correct judgments was required for the practice session and if not attained the practice session was repeated. All sessions commenced with a key-press by the participant. At the start of each trial a '+' sign was presented, and after a 500ms period the stimulus sequence was presented followed by the questions pertaining to that sequence. The participant response was unspeeded but could not be initiated until the end of the stimulus sequence. The response to the final question on each trial initiated the next trial. Participants were asked to keep response errors to a minimum. After the completion of half of the trials, a break (minimum 30s) was imposed. All of the experiments lasted between 30 and 45 minutes.

2.4 Results

Due to the nature of the data and the use of repeated measures analysis, the assumption of sphericity was, on occasion, violated (notification to the reader will be given at these times). The Huynh-Feldt correction was employed where appropriate. The data were also on occasions differentially distributed around the mean, creating a positively skewed distribution. When instances of this occurred, the data were transformed with a logarithmic function to create a more normal distribution prior to analysis. The occasions on which this transformation was employed are noted in the individual experimental chapters.

Chapter 3

Empirical Series 1: The Auditory Attentional Blink

3.1 Abstract

An initial series of three experiments was designed in order to examine the influence of perceptual organisation on the auditory attentional blink (AAB). First, it is shown that an AAB can be obtained (Experiment 1) using different stimuli and presentation software than that used in one recent study (Tremblay et al. 2005). An important part of the data in this study is the very high level of performance for all SOAs in both attention conditions; over 50% of the participants performed at ceiling (performance above 92% at all levels). However, with the removal of the participants at ceiling modality specific temporal deficits (the AAB) were evident, replicating the work of Tremblay et al. 2005. The subsequent experiments within this empirical series were designed in order to contribute to understanding of the mechanisms responsible for the attentional blink – as described further in the Introduction below. The principal manipulation in these studies was of acoustical factors. These acoustical factors relate to the context (the distractors) in which the targets are presented. It is shown that by increasing the number of distractor items (from 1 to 3) within the context, processing deficits comparable to those observed for the visual AB can be obtained (Experiment 1). However, maintaining distractor order is required to produce these effects (Experiment 2) as a random distractor order removes the AAB effect. The context also needs to be established through exposure to distractor items before the presentation of T1 (Experiment 3).

3.2.1 Introduction

The visual attentional blink (AB) is a robust phenomenon that has been the subject of more than 30 publications (e.g. Chun & Potter, 1995; Potter et al. 1998; Raymond et al. 1992; 1994; Shapiro et al. 1995, 1998). In contrast, only a small number of studies have shown a similar decrement purely within the auditory modality (Duncan et al. 1997; Mondor, 1998; Tremblay et al. 2005). Although the findings in these studies have challenged the idea that the AB is purely a visual phenomenon (Potter et al. 1998) there has been considerable variability in the paradigms employed. For example, Duncan et al. (1997) and Tremblay et al. (2005) used similar stimuli but a different method of presentation and obtained different results. Mondor (1998) used a different methodology again yet found similar results to Duncan et al. (see section 1.6 for a review of all of these experimental procedures). The motivation for this series of studies is to obtain evidence for the auditory attentional blink (AAB) using paradigms based on the work of Tremblay et al. (2005), and to use this finding as the basis for subsequent studies designed in order to distinguish between competing theoretical accounts of the attentional blink. A particular focus will be on the importance of the nature and sequencing of distractor stimuli that occur before as well as after targets T1 and T2.

3.2.1.1 The AAB paradigm

There are generally two classes of paradigm use to study the AAB. The major difference between these lies in the arrangement of the distractor items; these have been presented in either a random (Mondor, 1998) or a non-random order (Duncan et al. 1997; Tremblay et al. 2005). Although both paradigms can be employed in order to elicit the AAB, the experiments described here are based in the first instance on the work of Tremblay et al. because of their use of non-random distractor sequences. Random distractors place greater attentional demands on the task due to a lack of predictability. The masking potential of the +1 items, however, is fixed with random distractors, so the AAB should not change as the distractors (the context) change. By contrast, according to a streaming account (see Chapter 1, section 1.5), the properties of the +1 items change according to the nature of the context in which they are presented (Bregman & Rudnicky, 1975). Items sharing acoustical characteristics (e.g. a similar onset) are more likely to be considered similar and therefore part of the same perceptual unit or stream (Bregman, 1990). Therefore, according to a streaming account, both +1 items in a repeated distractor sequence (the repetition of a single distractor token) will be perceived as belonging to the rest of the distractor sequence, therefore reducing the masking potential in comparison to a random distractor condition.

3.2.1.2 Initial reports of the AAB

In the first published AAB study (Duncan et al. 1997), the distractor items were identical. Each item was presented for 150 ms with a 100 ms ISI. The stimuli were presented in two streams, and each stream contained one target. Temporally specific decrements were shown and the results were interpreted as an AAB, although it is hard to say with complete certainty that the effect is not simply due to a reduction in audibility, rather than a suppression of attentional processing. This is because the presentation rate of 4 items/s with large ISIs severely reduces the masking potential of the proceeding item. The two streams were also maximally offset (see Figure 1.5) resulting in temporal overlapping of the stimuli. This means that the beginning and end of each stimulus would have been masked by integration, whereas interruption masking is the norm for the visual modality (Enns et al., 2001; Shapiro et al., 1995; Visser et al., 1999). Additionally, the task for each target was to identify one of a target-pair. For example, if T2 was either 'cod' or 'cot' the difference between the two lies on the offset of the target, the area that overlaps the preceding item. In addition to the overlapping of items, pitch distinguished the targets from the distractors (i.e. distractors presented in a middle pitch with a high pitch T1 and a low pitch T2). This change in pitch (*pitch-shift*) has been classified as a switch across attentional set (Visser et al. 1997), and could therefore potentially contaminate any attentional deficits caused by processing interactions.

In an attempt to disentangle this apparent AAB from both a reduction in audibility and a switch cost, in the paradigm used by Tremblay et al. (2005, Experiment 2, see Figure 1.6) there was a single stream of stimuli. With the use of one stream a few changes were incorporated; first, the removal of the ISI, and second, targets and distractors were of the same pitch, therefore reducing any pitch-shift cost. Presenting the stimuli in one stream and at a faster rate increases the likelihood that the perceptual system will group similar items together (*cohesion*: Bregman, 1990). In an attempt to understand further the processes that affect cohesion, Tremblay et al.

2005 modulated the context provided by the distractors. As with Duncan et al. (1997), the repeated distractor 'guh' was used as well as a 3-item repeated distractor consisting of 'guh' 'gih' and 'gah' (hereafter referred to as the changing distractor condition) and a no distractor condition (only T1 and T2 presented). From a streaming perspective, the introduction of these differing distractors allows greater modulation of the context by increasing the likelihood that the distractors will group together, thereby allowing easier segregation of the targets from the distractors. Tremblay et al. 2005 demonstrated robust AABs (exhibiting lag 1 sparing) when the targets were presented within a context. In addition, the largest effect was produced with the repeated distractor condition, thereby highlighting the important influence of the context.

Mondor (1999) reported an AAB using a methodology comparable to that used to investigate the visual AB. The targets were embedded within a RAP composed of random distractors. Targets were differentiated from the distractors by pitch and timbre. Mondor's (1999, Experiment 1) data were very similar to those presented by Duncan et al. (1997)[2] whereby the correct identification of T2 was at its lowest when T2 was temporally adjacent to T1. Performance then gradually increased with the more items that intervened between the two targets.

This asymptotic relationship has been described as evidence for the existence of the AAB. However, as there was a change in task demands between the two targets, a reconfiguration cost could have been imposed on participants explaining at least in part the findings that were obtained.

3.2.1.3 Reducing switch costs

Random and non-random distractor sequences affect differently the listener's ability to detect order (Bregman & Campbell, 1971) and random distractors reduce the ability to remember order. The ability to reconstruct the sequence after listening is reduced due to a reduction in order cues available to the listener. This is important, as the AAB requires target order to be preserved. For this reason, paradigms that use random distractors have had to highlight the targets from the distractor sequence (Duncan et al. 1997), as in the visual domain (Chun & Potter, 1995; Raymond et al., 1992). This has been done in two different ways, firstly with the simultaneous presentation of a tone in one ear with the stimulus stream presented in the other

[2] However, Mondor's (1999) Experiment 2 did show a more traditional, 'U' shaped performance curve, with the T2 +1 item removed, although attenuated.

(Arnell & Larson, 2002), and secondly distinguishing the targets from the distractors by pitch (Duncan et al. 1997) or timbre (Mondor, 1998). The addition of a concurrent tone over the target stimuli may initiate a more positive orienting response, which in some way introduces contamination by either acoustical or attentional artefacts. Making the targets distinct from the distractors, on the other hand, may impose a reconfiguration of 'task-set'. This reconfiguration may reduce the ability to attend effectively, thus the observed performance decrements may not be directly attributable to between-task interference (crosstalk: Allport & Wylie, 1999). The use of an ordered context reduces contamination and increases segregation of targets from distractors.

3.2.1.4 Context: The target-distractor relationship

In the auditory domain, the patterns of the distractors (either random or non-random) directly affect the context in which the targets are presented (Tremblay et al. 2005). For the production of the AAB, both the target items require masking (Tremblay et al. 2005). Increasing exposure to the masking item, however (especially when using non-random distractors), affects the properties of the mask (Massaro, 1976). For example, with a repeated distractor the masking power of both the +1 items is reduced, as they are more likely to be grouped as to-be-ignored (TBI) due to exposure to the same item a number of times before the presentation of the targets. This preattentive segregation (see Chapter 1, section 1.5.1) reduces the attentional workload and makes it easier to distinguish targets from distractors (Bregman, 1990). The proper functioning of this system is vital for extracting information from a noisy environment by grouping acoustically similar sounds (e.g. a voice) into separate objects. The act of creating streams then reduces perceptual confusion, thereby allowing greater focus on the attentional mechanisms at work. Therefore, if the processing of the first target delays the subsequent processing of the second, greater access to the targets will more accurately chart time-dependent processing deficits.

The three experiments of this series were designed in order to understand the role of perceptual factors in the AAB, following from the work of Tremblay et al. The method described by Tremblay et al. 2005 is versatile as it allows manipulation of the context in which the targets are presented without imposing a switch cost, and close variants of this approach are employed throughout this thesis.

3.3 Experiment 1

Experiment 1 utilised the method outlined by Tremblay et al. 2005. All stimuli were presented in the same stream with a fixed order of target presentation; e.g. the target 'Cod' or 'Cot' always preceded 'Nab' or 'Nap' . The distractor sequences could either be homogenous, comprising a repeated 'Guh', heterogeneous (changing distractors) with the repetition of a cyclic set of 'Guh, 'Gih' and 'Gah' or empty (no distractors, only targets are presented). In line with previous AAB experiments, there were two attentional conditions. The focused attention condition required the identification of T2 only. The divided attention condition required the identification of both targets in the correct order.

As with Tremblay et al. (2005), the present experiment was designed in order to investigate the role of the context in which targets are presented. As already stated, the nature of the distractors influences the likelihood that they will group together (Bregman, 1990). As with the work of Tremblay et al., the present experiment will assume the same predictions in performance based upon the notion of perceptual organisation, acoustically similar items will tend to group together within streams (Bregman, 1990; Bregman & Rudnicky, 1975). The AAB should only be present in those conditions in which the targets are presented in a context. Any differences between the two distractor-present conditions will reflect the degree to which the distractor items group together.

The proposed differences between the distractor conditions relate to consideration of the level of homogeneity between distractor items. The changing distractor condition should elicit the largest effect (AAB) due to two factors; first, the fact that increasing the number of different distractor items reduces exposure to each individual item. The consequence of this is that the masking potential of the context is increased. The second is the fact that having a larger number of dissimilar items in each auditory sequence may increase the monitoring required for each sequence. This increased workload may influence the degree of confusion/competition in auditory STM (Tremblay et al. 2005). Another way of conceiving of this is that the repeated distractors will permit easier extraction of the target information as they will group together because of their similarity, and in combination with the increased (relative) ease of the task for the repeated distractor condition will result in a smaller AAB than in the changing distractor condition. Finally, a no distractor condition acts as a control whereby no distractor/target interaction can occur.

3.3.1 Method

3.3.1.1 Participants

17 volunteers (11 female), age range from 19 to 26 (mean age = 20.3) were recruited from Cardiff University; their participation was in exchange for course credit. Ten participants' data was excluded from the analysis due to their levels of performance exceeding pre-defined limits (see General Method section for criteria)

3.3.1.2 Materials

Each trial of the rapid auditory presentation (RAP) comprised auditory samples, all 130 ms in length. There were no blank (silent) periods between stimuli. Targets were either 'Cod' or Cot', and 'Nab' or 'Nap'. The order of target presentation was always fixed, e.g. if T1 was either 'Cod' or Cot', then T2 would always be either 'Nab' or 'Nap'. Distractor sequences (the context) comprised three separable groups; repeated (repetition of 'guh'), changing (cycling 'guh', 'gih' and 'guh') and no distractor sequences. T2 was presented after T1 at four SOAs; adjacent at 130 ms (lag 1), 260 ms (lag 2), 520 ms (lag 4) and 1170 ms (lag 9). 96 individual sequences were created, comprising eight trials of each combination of lag (4) and distractor condition (3). Six distractor items always preceded T1, whilst three items always followed T2. Timings for the T1-T2 SOAs in the no distractor condition were made equivalent to the other conditions by the addition of silent periods of appropriate durations.

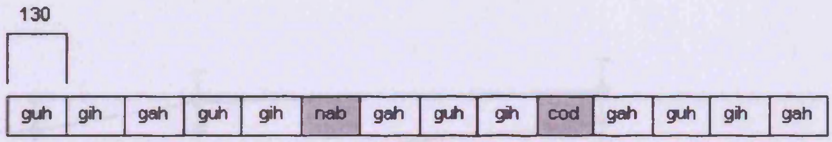

Figure 3.1: Graphical representation of single stream changing distractor auditory presentation.

3.3.1.3 Experimental design

The three repeated measures were attention (focused vs. divided: the detection of one versus the detection of both targets), SOA (130, 260, 520 & 1170 ms) and distractor type (repeated, changing & no distractor), all within participants and fully randomised. The experiment consisted of six blocks of 96 trials for the focused (3 blocks) and divided (3 blocks) conditions. There were 576 trials in total with a short break between each block. Participants alternated between focused and divided blocks, and 50% of the participants completed a focused block first.

3.3.1.4 Procedure

See General Methods section.

3.3.2 Results

The likelihoods of correct identification of T2 collapsed across distractor types for both attention conditions are presented in Figure 3.1. The figure shows an AAB performance curve broadly similar to that reported by Tremblay et al 2005, with a performance decrement at lag 2 in the divided condition.

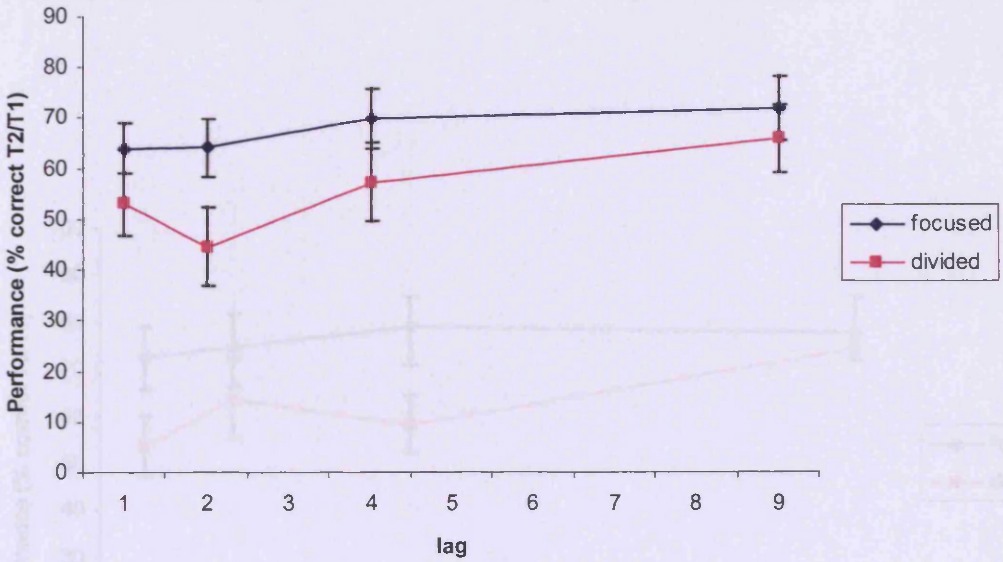

Figure 3.2: Overall performance collapsed across distractor type (error bars = +1/-1 mean standard error)

T1 performance: T1 was reported accurately on 85% of divided attention trials. A repeated measures ANOVA with distractor type (3 levels) and SOA (4 levels) was carried out on T1 performance and revealed no significant differences (all p's > 0.5). This suggests that T1 performance is unaffected by SOA and distractor type.

T2 performance: The data were adjusted for within condition variance using a logarithmic function (for detailed justification, see General Methods). When the assumption of sphericity was violated a Huynh-Feldt (1976) correction was employed, and corrected degrees of freedom are given in the text (for explanation see General Methods, section 2.4). The initial repeated-measures ANOVA incorporating all distractor types revealed significant main effects of attention $F(1,6) = 10.216$, $mse = .577$, $p < .02$, distractor type $F(1.02,6.12) = 9.798$, $mse = .364$, $p < .02$ and SOA $F(1.30,7.92) = 10.716$, $mse = .350$, $p < .01$. These effects were modulated by significant interactions between attention and SOA $F(1.30,7.81) = 10.716$, $mse = .330$, $p < .01$, and distractor type and SOA $F(1.17,7) = 6.007$, $mse = .179$, $p < .01$, as well as an interaction between all three factors $F(2.64,15.86) = 6.889$, $mse = .132$, $p < .005$.

To understand further the influence the distractor context exerts upon target detection, further analysis was carried out separately for each distractor condition.

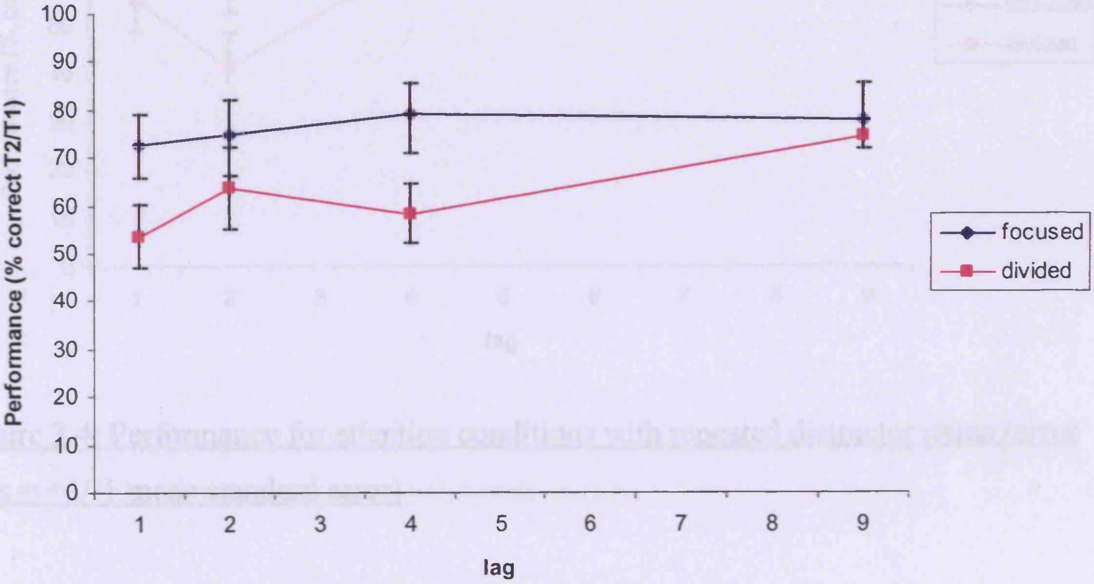

Figure 3.3: Performance for attention conditions with no distractor items (error bars = +1/-1 mean standard error)

Fig. 3.3 shows the likelihood of correct T2 identification in the no distractor condition. An ANOVA revealed main effects of attention $F(1,6) = 13.752$, $mse = .007$, $p < .01$ and SOA $F(3,18) = 6.784$, $mse = .001$, $p < .005$, reflecting the fact that accuracy increased with lag and was superior in the focused condition. The interaction between attention and SOA approached significance $F(1.21,7.23) = 4.837$, $mse = .603$, $p < .06$. A planned comparison (t-test) to investigate lag 1 sparing comprised a direct contrast between the size of the performance decrement in the divided relative to the focused condition at lags 1 and 2. The non-significant result revealed no evidence for lag 1 sparing (M = 8.929, SD = 15.106), t(6) = 1.564, $p > .05$.

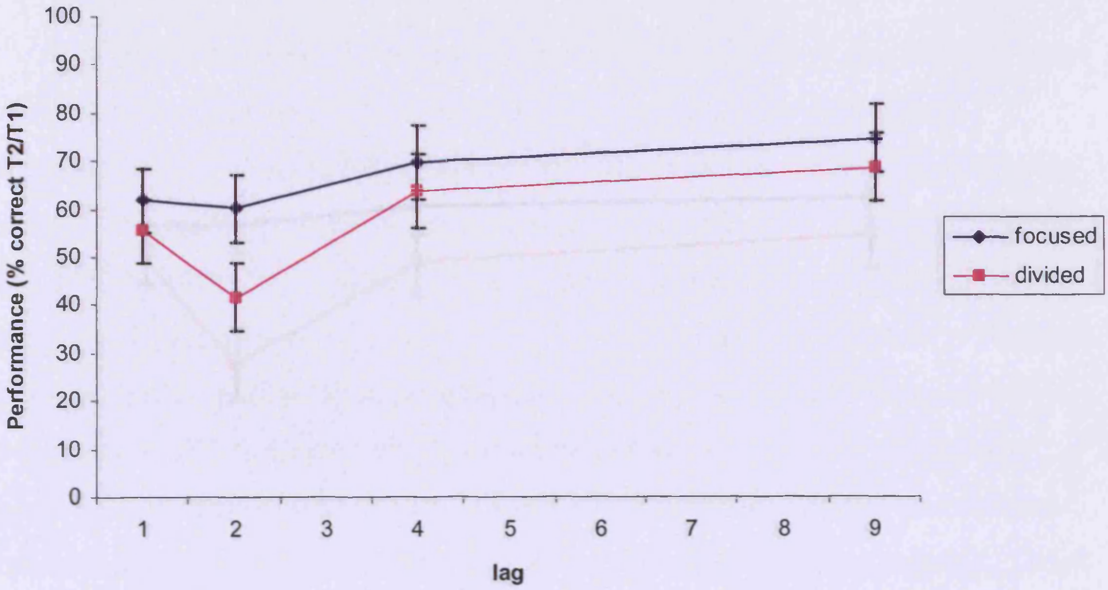

Figure 3.4: Performance for attention conditions with repeated distractor items (error bars = +1/-1 mean standard error)

The same analysis was carried out on the repeated distractor condition (see Fig. 3.4) and revealed a main effect of SOA only $F(1.61,9.66) = 11.563$, $mse = .121$, $p < .005$, reflecting an increase in accuracy as lag increases. The planned comparison across lags 1 and 2, however, revealed evidence for lag 1 sparing, (M = -11.905, SD = 12.367), $t(6) = 2.547$, $p < .05$.

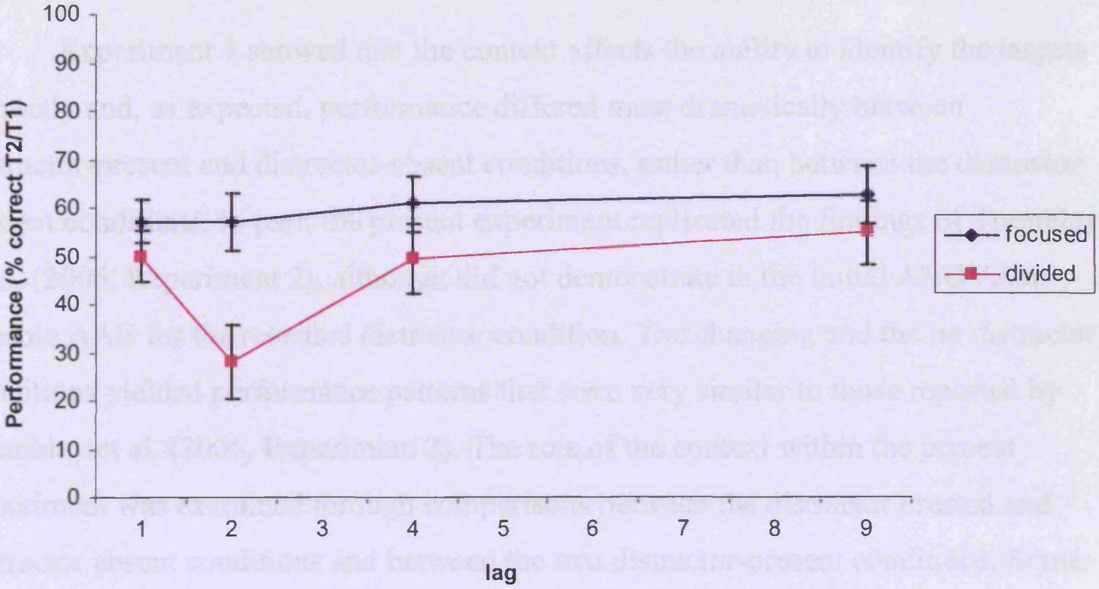

Figure 3.5: Performance for attention conditions with changing distractor items presented (error bars = +1/-1 mean standard error)

The analysis for the changing distractor condition (see Figure 3.5) revealed a main effect of condition $F(1,6) = 12.577$, $mse = .296$, $p< .02$, and SOA $F(1.31,7.84) = 9.403$, $mse = .377$, $p< .02$, as well as a significant interaction between condition and SOA $F(2.23,13.39) = 10.625$, $mse = .158$, $p< .005$. The interaction – the statistical signature of the attentional blink – reflects the fact that the size of the performance decrement at lag 2 in the divided attention condition compared to the focused condition is markedly larger than at all other lags. The planned comparison to assess lag 1 sparing revealed that the performance decrement at lag 2 was larger than the decrement at lag 1 (M = -22.024, SD = 13.547) $t(6) = 4.301$, $p< .005$. It should be noted that the size of the effect demonstrated in Figure 3.5 is smaller than that of the visual AB.

In summary, the three-way interaction involving distractor condition that came about in the initial global analysis reflects the fact that robust statistical evidence for an AAB was obtained only in the changing distractor conditions, although the data in the repeated condition show a similar pattern.

3.3.3 Discussion

Experiment 1 showed that the context affects the ability to identify the targets correctly and, as expected, performance differed most dramatically between distractor-present and distractor-absent conditions, rather than between the distractor present conditions. In part, the present experiment replicated the findings of Tremblay et al. (2005, Experiment 2), although did not demonstrate in the initial ANOVA a reliable AAB for the repeated distractor condition. The changing and the no distractor conditions yielded performance patterns that were very similar to those reported by Tremblay et al. (2005, Experiment 2). The role of the context within the present experiment was examined through comparisons between the distractor present and distractor absent conditions and between the two distractor-present conditions. Some evidence for an AAB was demonstrated for both distractor present conditions; therefore, one can infer that a context is required to elicit the AAB, in keeping with conclusions drawn based on findings in the visual modality (Raymond et al., 1992).

3.3.3.1 Context: The T-D relationship

The context in which the target is presented has a great influence upon SOA dependent interactions. As predicted, participants performed differently depending upon the T-D relationship with respect to both the type and the presence or absence of distractors. The difference between the distractor present conditions allows investigation of perceptual factors, masking and/or streaming, that may influence the likelihood of target identification. In both the changing and repeated conditions, both targets were masked by +1 items. However, the masking potential of the +1 item was modulated due to the properties of the surrounding distractor items. If the role of the context were simply to mask the targets there would be no difference between repeated and changing distractor conditions. However, Experiment 1 demonstrated some differences between distractor conditions, suggesting the way in which the distractor items behave across conditions directly effects target identification. In this experiment, however, these claims are tempered by the apparent similarity between the findings in the two conditions and the lack of statistical power imposed by virtue of the low number of participants included. These issues are returned to in section 3.6.1.

From the concept of streaming, presenting the targets within a distractor sequence allows greater segregation from the irrelevant distractor information (Bregman & Rudnicky, 1975). Both distractor-present conditions create a pre-target context by way of the six items occurring before the onset of T1. Establishing this context allows greater segregation of the targets from the context; the targets are more likely to 'pop-out'[3]. The number of different items and the order in which they are presented affects the number of potential streams formed. Sounds come from different sources, and sounds from the same source tend to share acoustic similarities. This information is used as one basis for organising stimuli into separate streams, representing different objects. With just one repeating item, one defined stream is formed based on acoustic similarity. With three repeating items, the contextual field becomes denser. With very little exposure, the three items will be defined by their whole; the participants perceive a repetition of the 'guh-gih-gah' sequence. Therefore, the 3-item percept will be stronger than each individual item. However, after a number of exposures to the sequence, the items will group together based on similarity, forming three streams. Increasing the number of streams reduces the ease with which the targets pop-out, thus increasing difficulty. This account, based on the principles of auditory segregation (Bregman, 1990), offers to explain why the AAB is more pronounced in the changing than in the repeated condition, and performance differences due to these two types of distractor sequence will be returned to in later sections of this thesis.

3.3.3.2 Lag 1 sparing

The presence of a reliable lag 1 sparing effect is required to demonstrate the existence of a 'true' AB (Chun & Potter, 1995; Potter, et al. 1998; Visser, et al. 1999 – although see Arnell, 2001 for alternative explanation). The present experiment demonstrated reliable lag 1 sparing effects for both the distractor-present conditions (largest in the changing distractor condition). Lag 1 sparing was the major difference between this study and that of Duncan et al. (1997), demonstrated in the comparable repeated distractor condition, as described earlier (see section 3.2.3), and possibly due to a switch imposed in target pitch.

For lag 1 sparing to be demonstrated, it has been shown that the two targets need to originate from a similar set; that is, if changes in task, category, location or

[3] The idea of pop-out refers to the extraction of target information from a sequence in relation to the non-target items: with no distractor there can be no pop-out.

modality are enforced then lag 1 sparing is not obtained (Chun & Potter, 1998; Enns et al., 2001; Visser et al., 1999). From auditory cuing experiments (e.g. Mondor & Bregman, 1994; Mondor & Lacey, 2001; Schat, Quigley, Aoki, Peachey & Reeves, 1987) a cue of the same frequency and intensity as the target increases identification accuracy, thus the focusing of auditory attention modulates auditory perception (Dalton & Lavie, 2004). With no cueing, the no-distractor condition performance at lag 1 is decreased. One might then assume that T1 and T2 are effectively separate units hence a reconfiguration (or switch) cost is incurred. An immediate drop in performance followed by a gradual monotonic recovery as the temporal distance between targets increases – which is what was obtained in the no-distractor condition - highlights this reconfiguration cost (Allport & Hsieh, 2001).

In summary, the present study highlights the influence of the distractor items and the context they provide. The provision of a context has been shown to be vital for the production of the AAB. The context allows both targets to be perceived as more similar, allowing capture of both items when presented contiguously and providing competition for processing resources when presented within the same temporal period (100 – 400 ms) as the visual AB. Increasing the number of different items in the distractor sequence (from one to three) results in a larger AAB. Experiment 2 was designed in order to investigate the influence of order within the distractor item context by introducing a random distractor sequence.

3.4 Experiment 2

The aim of the present experiment was to understand further the role of perceptual organisation in the AAB. Specifically, the role the order of distractors plays in the AAB. This is attempted by the inclusion of a random-distractor sequence along with the repeated and changing distractor sequences. From Experiment 1, it was shown that AB like performance could be demonstrated in the auditory domain when both the targets are masked (i.e. presented within a context). As mentioned in a previous section (see 3.2.1.1), the masking potential of both the +1 items is modulated by the context in which they are presented. If, as shown in the previous experiment, it is merely the presence of distractors and not the order in which they are presented that is important for the AAB, then the AAB will be demonstrated in all conditions. Specifically, if the production of the AAB relies only or primarily on the physical input of acoustical information after T2 (masking, in relation to Tremblay et al, 2005, Exp. 1) then no effect of distractor type will occur. However, if the allocation of perceptual events into streams is important for the AAB, then the AAB will be affected by whether the order in which the distractors are presented promotes streaming (repeated and changing) or not (random). The comparison between ordered and non-ordered distractor sequences thus provides one means of assessing influences due to masking and streaming.

The random distractor condition presumably creates a dense auditory scene (Bregman, 1990). That is, the likelihood that T1 and T2 will be preceded by a different item across trials is increased compared to the relative predictability of the repeated and changing conditions. A random distractor sequence creates a similar target context to those in analogous RSVP paradigms (Arnell & Jolicoeur, 1995, 1999; Arnell & Larson, 2002; Mondor, 1998).

Interestingly, published AAB studies that have utilised random distractor presentation have not yielded lag 1 sparing (Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Mondor 1999, Exp. 1). In the present experiment, as in Experiment 1, there is no pitch or stimulus set switch between T1 and T2. Additionally, the targets are not contaminated by additional cues to aid capture of the targets, as in the studies of Arnell & Larson (2002) and Mondor (1999) mentioned earlier (section 1.6). Therefore, if lag 1 sparing for the auditory modality is similar in its mechanism to the visual modality, performance at lag 1 should be no different across attention and distractor conditions. However, if the ways in which sounds are grouped and segregated somehow promotes lag 1 sparing in the AAB, the removal of order within the context should remove the lag 1 sparing effect.

The stimulus set from the previous experiment was used and contained the repeated and changing conditions. The third variant, a random distractor sequence, used 'gah', 'geh', 'gih', 'goh' and 'guh'. It was necessary to increase the set size in order to create a more variable series because a random distractor sequence with only three distractor tokens has a very high chance of creating a sequence that is similar to both the repeated and changing conditions. The new stimuli are very similar to the distractors used previously, the only difference being the middle vowel in each three-letter string.

There was an additional methodological change between the present experiment and Experiment 1 which was the use of only three T1-T2 SOAs; lags 1, 2 and 9. In the previous experiment, it was shown that for the changing distractor condition the largest performance deficit occurred at lag 2, with performance at lags 1, 4 and 9 being approximately equal.

3.4.1 Method

3.4.1.1 Participants

19 (8 female) students, age range from 18 to 26 (mean = 19.4) from Cardiff University received a small honorarium in exchange for their participation. Nine participants' data was excluded from the analysis due to their levels of performance exceeding pre-defined limits (see General Methods).

3.4.1.2 Materials

The same stimulus lengths and target orders as Experiment 1 were used, but the stimulus set was larger. Six distractors items always preceded T1. T2 was presented after Tl at three SOAs, 130 ms (lagl), 260 ms (lag 2) and 1170 ms (lag 9). Three distractor conditions were used; repeated (contained only 'guh'), changing ('guh, 'gih' and 'gah') and random ('gah', 'geh', 'gih', 'goh' and 'guh').

3.4.1.3 Experimental Design

The experiment consisted of 6 blocks of 72 trials, producing 432 trials in total.

3.4.1.4 Procedure

See General Methods section.

3.4.2 Results

Figure 3.5 shows the likelihood of correctly identifying T2 for both attention conditions, collapsed across distractor types. The figure shows markedly lower performance in the divided than in the focused condition, with some indication of the deficit being largest at lag 2.

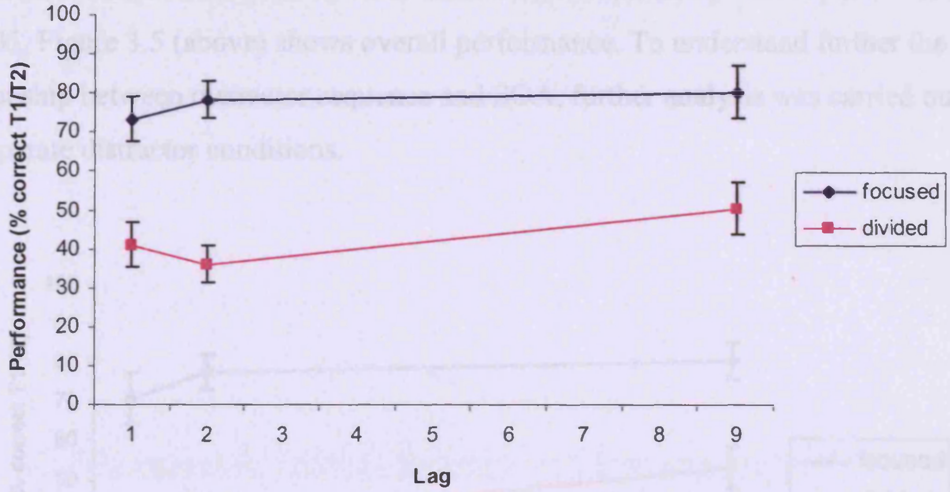

Figure 3.6: Overall performance for all participants collapsed across distractor types (error bars = +1/-1 mean standard error)

T1 performance: On average T1 was reported correctly on 82.3% of the divided attention trials. A repeated measures ANOVA with factors of distractor type (3 levels) and SOA (3 levels) was carried out on T1 performance and revealed only a significant main effect of distractor type only $F(2,18) = 4.237$, $mse = 87.787$, $p < .05$. T1 performance differed between the random distractor (M = 79.532, S.E. = 5.307) and the repeated (M = 84.503, S.E. = 4.052[4]) and changing M = 83.041, S.E. = 4.792) distractor conditions. The fact that T1 performance is affected by distractor type (unlike Experiment 1) should not influence the findings concerning the AAB as performance in which T1 is incorrect is not included in the T2 analysis (further discussion of the implications of these changes in T1 performance is contained in Chapter 7, section 7.1.1.8)

T2 performance: The data incorporating all distractor types was submitted to a repeated measures ANOVA (due to the violation of sphericity, adjusted degrees of freedom will be given: see General Methods section 2.4 for explanation) and revealed significant main effects for condition $F(1,9) = 238.747$, $mse = .768$, $p < .001$ and SOA $F(1.301,11.706) = 9.360$, $mse = .111$, $p < .01$. These effects were moderated by

[4] Means (M) and standard errors (S.E.) represent estimated marginal means

significant interactions between attention and SOA $F(2,18) = 9.744$, $mse = .049$, $p = .01$, and distractor type and SOA $F(3.061,27.533) = 7.832$, $mse = .065$, $p = .001$, as well as an interaction between all three factors $F(2.793,25.138) = 5.773$, $mse = .060$, $p < .005$. Figure 3.5 (above) shows overall performance. To understand further the relationship between distractor sequence and SOA, further analysis was carried out on the separate distractor conditions.

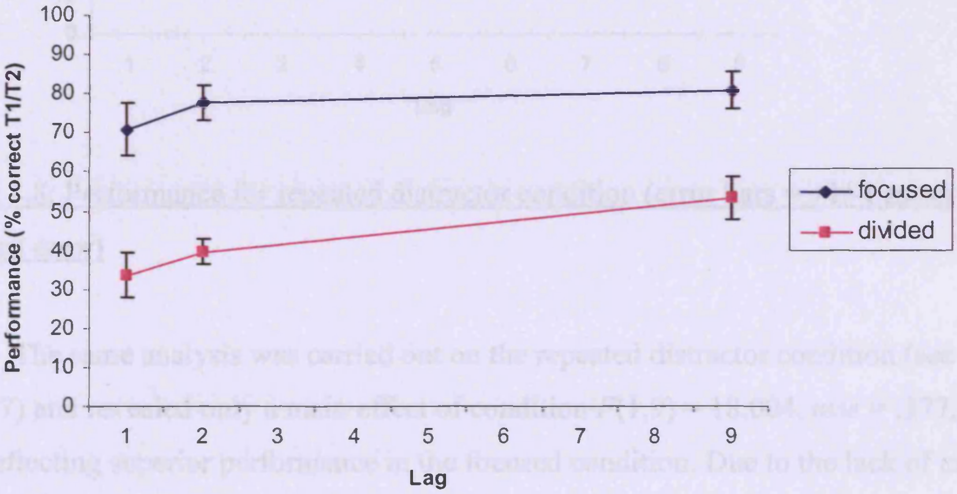

Figure 3.7: Performance for random distractor condition (error bars = +1/-1 mean standard error)

Performance data for the probability of correctly identifying T2 in the random distractor condition (fig. 3.6) was submitted to a repeated-measures ANOVA. The analysis revealed only main effects for condition $F(1,9) = 20.723$, $mse = .326$, $p < .001$ and SOA $F(2,18) = 16.967$, $mse = .039$, $p < .001$ highlighting the fact that performance was better with increasing numbers of distractors and better in the focused than in the divided attention condition.

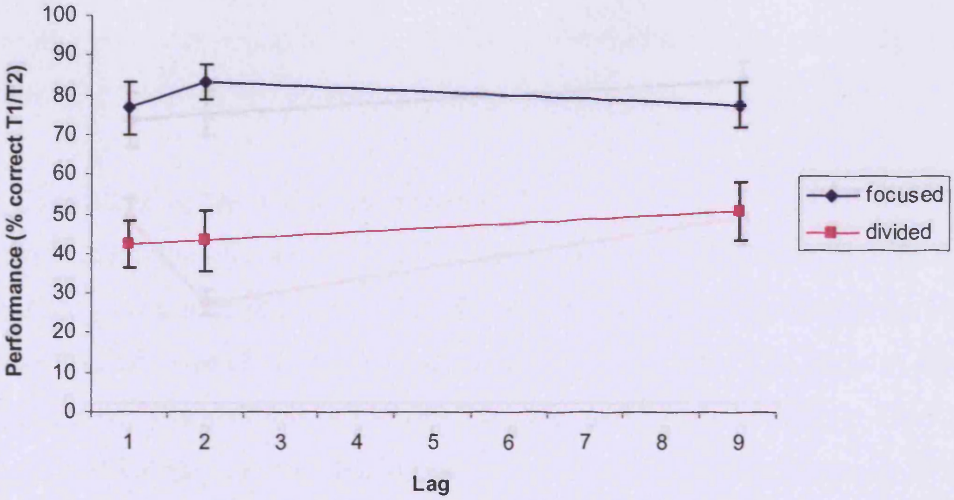

Figure 3.8: Performance for repeated distractor condition (error bars = +1/-1 mean standard error)

The same analysis was carried out on the repeated distractor condition (see Fig. 3.7) and revealed only a main effect of condition $F(1,9) = 18.004$, $mse = .377$, $p < .005$ reflecting superior performance in the focused condition. Due to the lack of an interaction, no further analysis was carried out.

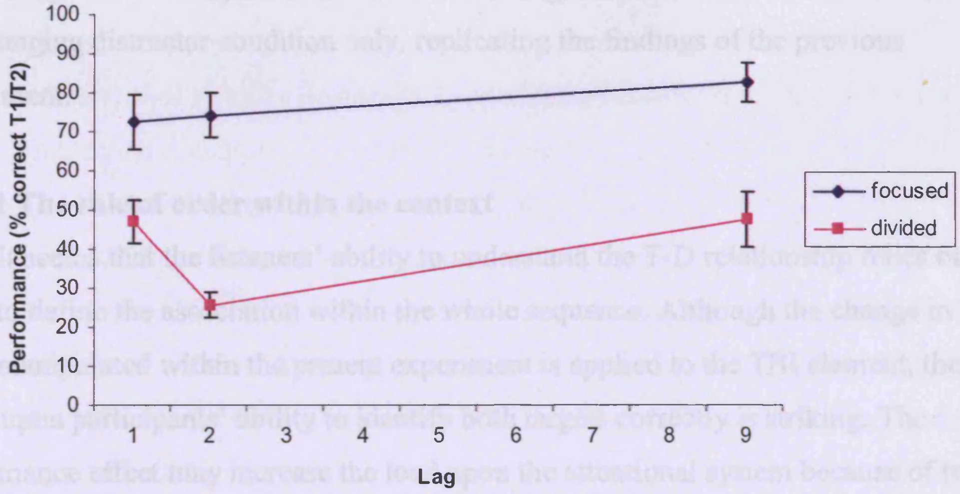

Figure 3.9: Performance for changing distractor condition (error bars = +1/-1 mean standard error)

The analysis of performance for the changing distractor condition (see Fig. 3.8) revealed a main effect for condition $F(1,9) = 26.289$, $mse = .328$, $p = .005$ and SOA $F(2,18) = 8.795$, $mse = .084$, $p < .005$ plus a significant interaction between these factors $F(2,18) = 15.688$, $mse = .041$, $p < .001$. This pattern of data replicates the findings from the changing distractor condition of Experiment 1. In addition, a planned comparison replicated the effect of lag 1 sparing (M = -22.083, SD = 11.711) $t(9) = 5.963$, $p < .001$.

To summarise, the three-way interaction between attention condition, distractor type and SOA arising from the initial analysis of overall performance is because only the changing distractor condition shows evidence of an AAB.

3.4.3 Discussion

Experiment 2 manipulated order within the context, which had a direct impact upon the AAB. The lack of an AAB for the random distractor condition may be due to the removal of order from the context. According to principles of auditory perception (Bregman, 1990; Bregman & Rudnicky, 1975), the removal of order would affect the perception of the targets in two ways; first, by reducing the potential for the distractor items to group together, and second, by increasing the masking potential of the +1 items. The results suggest that the targets require a context with a certain amount of irregularity as well as a particular level of masking, because the AAB was evident in the changing distractor condition only, replicating the findings of the previous experiment.

3.4.3.1 The role of order within the context

It seems that the listeners' ability to understand the T-D relationship relies on order to define the association within the whole sequence. Although the change in order manipulated within the present experiment is applied to the TBI element, the effect upon participants' ability to identify both targets correctly is striking. The performance effect may increase the load upon the attentional system because of two factors; first, the increase in numbers of items within the random distractor sequence, and second, the way in which order affected the resulting segregation (grouping items into streams). Increasing the number of items within the random distractor sequence increases the likelihood of a change in timbre across time, thus creating a denser auditory scene requiring more rigour scanning. In addition, the increase in timbre reduces the difference between the target and distractors, again increasing the difficulty of the task. Reducing the regularity within the sequence increases the likelihood that items resist assignment to the same sub-stream (Bregman, 1990), again increasing the difficulty of extracting target information.

The term 'context' refers to the structure and nature of the auditory sequence within which targets are embedded. The role of the context is to determine the processing afforded and allocated to targets. The removal of order reduces the cohesion between distractor items, therefore decreasing the likelihood that the context will, according to streaming principles, form sub-streams. However, simply presenting auditory items, related by temporal, not acoustical similarity, is not enough to elicit the AAB, as removing the order of the context produces a similar level of performance to that observed when no context was presented (see Fig. 3.2). If the removal of order increased the perceptual load, i.e. a distractor or target, is more likely to be considered as a separate event, speeding up the locus of selection reducing the interference this increases the demands placed upon attentional resources. A consequence of processing items sequentially would be the largest decrement in performance when T2 is presented directly after T1, as is highlighted by the linear relationship between SOA and identification performance in the random distractor condition (see Fig. 3.6). According to these assumptions, the attentional system is loaded most heavily when the two targets are adjacent, possibly resulting in the most interference, hence the performance decrement. In summary, according to this account, the removal of order decreases the similarity between the targets, thereby creating the perception of the two targets as separate events. The outcome of this is elimination of lag 1 sparing and consequently elimination of the AAB.

For the VAB, perhaps the most obvious correspondence to this is that fact that the VAB is attenuated when there is no categorical relationship between targets and distractors (Raymond et al., 1994; Visser et al., 1997). A second is the fact that the magnitude of the VAB increases along with the number of distractors in the sequence (Raymond et al., 1992).

3.4.3.2 Lag 1 sparing

Only the changing distractor condition demonstrated this lag 1 sparing effect. The exhibition of Lag 1 sparing may represent the 'accidental' capture of T2 when presented directly after T1 with no loss in identification (Visser et al 1999). Therefore, the existence of lag 1 sparing would signify a similar computational pathway in audition as that of the visual modality (Chun & Potter, 1995; Nieuwenhuis et al., 2005 Visser et al., 1999). These assumptions about the factors affecting lag 1 sparing were made for the most part, however, based on work on the visual AB[5]. These may not apply equally for the auditory modality. However, the removal of order reduced or abolished completely the effect of lag 1 sparing in a task with no task switch. This lack of lag 1 sparing has been shown on many occasions when random sequences of distractors are used in the auditory modality (Arnell & Jolicoeur, 1995, 1999; Arnell & Larson, 2002, Jolicoeur, 1998; Mondor, 1999). Each of these studies employed a switch of some sort and this was thought to cause the elimination of lag 1 sparing. The results from the present study suggest that for the auditory modality, lag 1 sparing is not determined by whether a switch has been imposed but by the context in which the targets are presented. Thus providing some kinds of order within the context increases the likelihood that lag 1 sparing will occur.

[5] The work carried out by Visser et al. (1999) concerning lag 1 sparing utilises a meta-analysis of data from cross modal (visual, auditory and tactile) and within-modality (visual and auditory) studies. However, the conclusions concerning the auditory modality relied on data from only one auditory modality study.

The issue of lag 1 sparing is discussed further in section 3.6.1, but now the focus turns to an examination of another factor, which may be important in the generation of the AB, and particularly the AAB. A factor that has not received attention within the visual AB literature is the items presented before T1. It is standard procedure in the visual AB for the number of items occurring before T1 not to remain the same, although typically no mention of the influence (if any) of this variation on target, identification is given. The previous experiments have highlighted the impact of the context upon target identification, but at what point does this contextual effect begin; are the items before T1 redundant? Experiment 3 was designed in order to examine the influence of items before T1 (*pre-T1* items) on the AAB.

3.5 Experiment 3

The motivation for the present investigation was to understand the role of the pre-T1 items. At issue is the amount of exposure to these items that is necessary in order to elicit an AAB. As noted in Chapter 1, the RSVP is assumed to rely on backward masking from the items occurring after the targets (Enns et al. 2001), whereas items occurring before the targets affect streaming (Bregman, 1990). The random distractor sequence removes order and decreases predictability, thus decreasing the possible cohesion of items into streams. On the other hand, reducing the number of items in the sequence to one (the repeated distractor condition) greatly increases predictability and therefore is very likely to form streams. Critically, knowledge about the predictability of a sequence accrues through exposure to that sequence. For example, one can predict the next item in the repeated sequence after a minimum exposure of two items, whereas the changing distractor would require a minimum exposure of six items. Thus according to streaming principles pre-T1 items are an important component of the AAB paradigm. This experiment was designed to investigate changes in the AAB according to the amount of exposure to distractors prior to T1.

In the previous experiment, an effect of SOA was evident when the targets were presented within a changing distractor sequence and there were six pre-T1 items. Additionally, no effect of SOA is evident in no distractor conditions (see Tremblay et al., 2005, Exp. 2). This suggests that the items that occur before the target affect processing differences according to SOA.

The pre-T1 context was manipulated by the presentation of six, three and zero items before T1. This means that the listener was exposed to no items before T1, one cycle of the distractors or two cycles of the distractor. With no exposure to the distractors, performance for T1 should be similar to that of the no distractor condition of Experiment 1. Any differences in performance between the three and six pre-T1 items would signal the importance of the pre-T1 sequence for the AAB.

3.5.1 Method

3.5.1.1 Participants

17 (10 female) students from Cardiff University aged between 18 and 28 (mean age 19.8) received a small honorarium for their participation. Eleven participants' data was excluded from the analysis due to their levels of performance exceeding pre-defined limits

3.5.1.2 Materials

The same stimulus lengths, targets and target orders as the changing distractor condition ('guh', 'gih' and 'gah') from Experiment 2 were used. Three pre-T1 item conditions were used; zero pre-T1 items, three pre-T1 items and six pre-T1 items. T2 was presented after T1 at three SOAs, 130 ms (lag1), 260 ms (lag 2) and 1170 ms (lag 9).

3.5.1.3 Experimental Design

The experiment consisted of six blocks of 72 trials, producing 432 trials in total.

3.5.1.4 Procedure

See General Methods section.

3.5.2 Results

Figure 3.9 shows the likelihood of correct T2 identification for both attention conditions collapsed across the number of pre-T1 items.

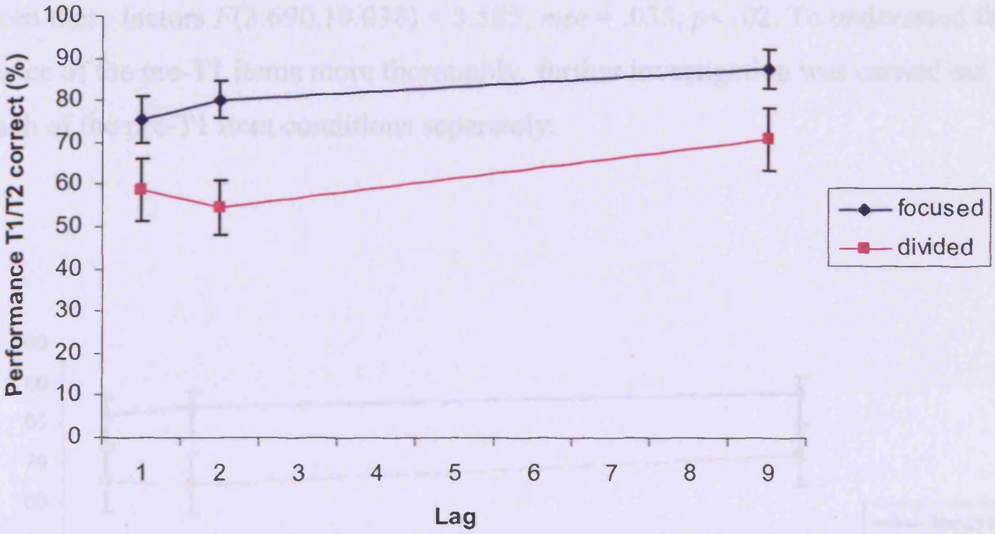

Figure 3.10: Overall performance for all participants collapsed across number of pre-T1 items (error bars = +1/-1 mean standard error)

T1 performance: On average, T1 identity was reported correctly on 88.66% of the trials in the divided-attention condition. A repeated-measures ANOVA with number of pre-T1 items (3 levels) and SOA (3 levels) was carried out on T1 performance and revealed only a significant main effect for number of pre-T1 items $F(2,15) = 3.306$, $p < .005$. The main effect came about because the likelihood of a correct T1 response was lower for both the zero pre-T1 item (M = 76.225, S.E. = 4.509) and three pre-T1 item (M = 77.044, S.E. = 5.456) conditions than for the six pre-T1 item condition (M = 82.292, S.E. = 5.232). . As with Experiment 2, the overall effect of differences in T1 performance should not influence the AAB because T2 accuracy is computed only for trials on which a correct T1 judgment was made. However, this does not, mean that all correct T1 judgments were associated with equivalent processing, a point to which will be returned to in section 7.1.1.8.

T2 performance: Data was initially analysed using a 3-way repeated measures ANOVA including all pre-T1 conditions. The analysis revealed significant main effects for attention $F(1,5) = 9.241$, $mse = 1.177$, $p < .01$, pre-T1 items $F(1.812,28.996) = 26.240$, $mse = .004$, $p < .001$ and SOA $F(1.652,8.427) = 10.265$, $mse = .145$, $p < .001$. These effects were modulated by significant interactions between attention and SOA $F(1.894,9.312) = 4.960$, $mse = .058$, $p < .02$, pre-T1 items and SOA $F(3.055,18.883) = 9.710$, $mse = .046$, $p < .001$, as well as the 3-way interaction between these factors $F(3.690,19.038) = 3.585$, $mse = .035$, $p < .02$. To understand the influence of the pre-T1 items more thoroughly, further investigation was carried out for each of the pre-T1 item conditions separately.

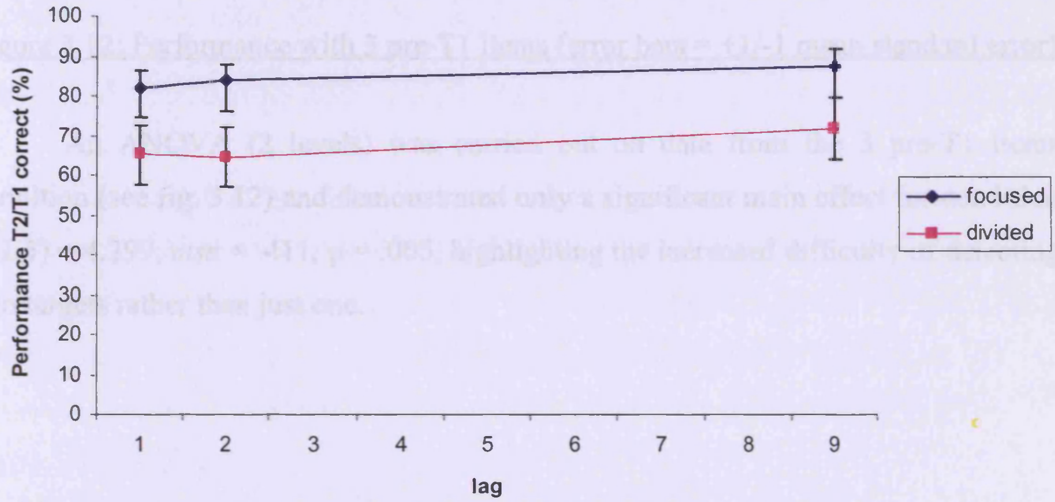

Figure 3.11: Performance with 0 pre-T1 items (error bars = +1/-1 mean standard error)

Figure 3.11 shows the probability of correct identification of T2 for both attention conditions with 0 pre-T1 items. An ANOVA (2 levels) revealed only a significant main effect for condition $F(1,5) = 8.714$, $mse = .309$, p = .009. The effect of SOA and the subsequent interaction were non-significant ($p > .05$) reflecting the fact that the task for the divided attention condition is more difficult than the focused attention condition, irrespective of the number of items intervening between the two targets.

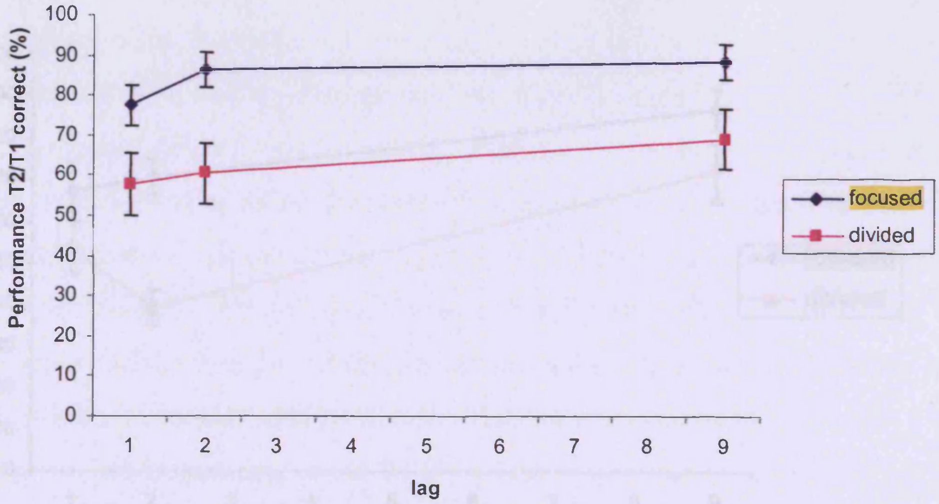

Figure 3.12: Performance with 3 pre-T1 items (error bars = +1/-1 mean standard error)

An ANOVA (2 levels) was carried out on data from the 3 pre-T1 items condition (see fig. 3.12) and demonstrated only a significant main effect for condition $F(1,5) = 4.299$, $mse = .411$, $p = .005$, highlighting the increased difficulty of detecting two targets rather than just one.

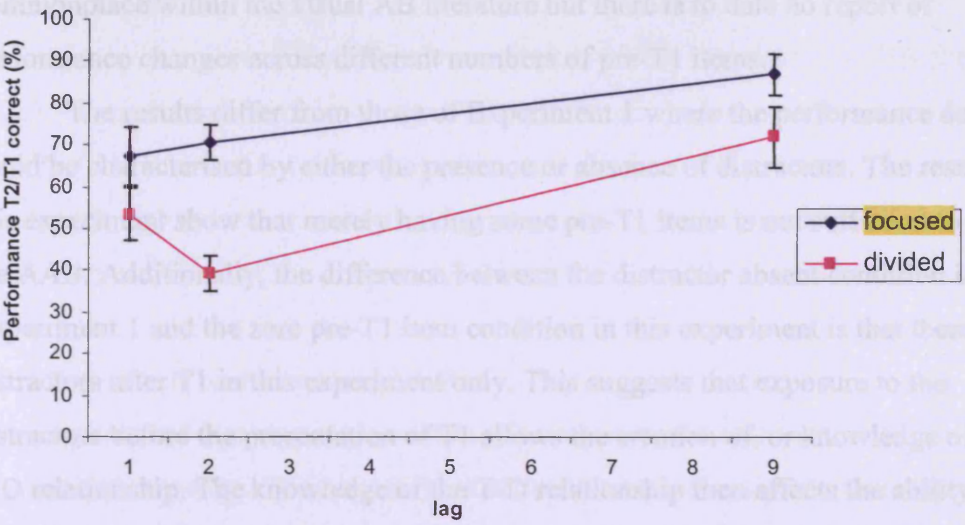

Figure 3.13: Performance with 6 pre-T1 items (error bars = +1/-1 mean standard error)

The analysis for the 6 pre-T1 items revealed a significant main effect for condition $F(1,16) = 7.546$, $mse = 530$, $p< .02$, SOA $F(1.645,8.315) = 17.115$, $mse = .113$, $p< .001$ and a significant interaction between condition and SOA $F(1.558,8.921) = 7.898$, $mse = .007$ $p< .005$ – the statistical signature of the AAB. A planned comparison revealed evidence for lag 1 sparing (M = -17.441, SD = 22.426) $t(5) = 3.207$, $p = .005$.

3.5.3 Discussion

The results of Experiment 3 provided more evidence for the role of the context upon the AAB, specifically the exposure to the context before the presentation of the targets. The existence of the AAB was confirmed by the replication of the findings for both the previous experiments when six items preceded T1 and the targets were presented within a changing distractor. The amount of exposure to the context before targets are presented dramatically affects the ability to identify the targets correctly. To elicit the AAB a certain exposure to the three-item distractor pattern is required. One could say that the minimum amount of exposure to know that the sequence is repeated would be two cycles, in this case meaning six items. In addition, the exposure to pre-T1 items may introduce timing strategies to orientate the attentional system (Reiss-Jones, 1999). Manipulation of the number of pre-T1 items is commonplace within the visual AB literature but there is to date no report of performance changes across different numbers of pre-T1 items.

The results differ from those of Experiment 1 where the performance data could be characterised by either the presence or absence of distractors. The results in this experiment show that merely having some pre-T1 items is not sufficient to elicit the AAB. Additionally, the difference between the distractor absent condition in Experiment 1 and the zero pre-T1 item condition in this experiment is that there are distractors after T1 in this experiment only. This suggests that exposure to the distractors before the presentation of T1 allows the creation of, or knowledge of, the T-D relationship. The knowledge of the T-D relationship then affects the ability to identify the targets correctly. The T1 performance data highlights this fact whereby the only factor to influence the likelihood of correctly identifying T1 was the number of pre-T1 items.

The data from the present experiment would suggest a certain level of exposure to distractors, in a sense a threshold, is required to elicit the AAB. The threshold may be a representation of the entirety of a sequence, whereby performance changes are related to how well the repetitive nature of a sequence has been established. The idea from Experiment 1 - that the reduction in performance at lag 2 is due to the binding of the 3-item distractor sequence within the first few repetitions - gains more weight from the evidence from the current experiment. The evidence suggests that early in the changing distractor sequence the items bind as a perceptual unit, rather than forming separate sub-streams, which happens after increased exposure to the sequence. The decrement in performance at lag 2 may relate to the difficulty for the attentional system in extracting information from strongly bound perceptual units.

3.6 General discussion

The experiments within this series provide important information about the antecedents of the AAB. The context in which the targets were presented had a dramatic influence upon the likelihood of correctly identifying the targets. The AAB effects reported previously were replicated with certain parameters, most notably when targets were presented within the changing distractor sequence and when six items preceded T1. The AAB is abolished with the removal of order within the context (Experiment 2) or if T1 is presented in a partial context (Experiment 3). Lag 1 sparing, a prerequisite of the AB (Chun & Potter, 1995), was demonstrated reliably (changing distractor conditions with six items preceding T1; Experiments 1, 2 & 3), however the effect was eliminated by the removal of order (Experiment 2) without imposing a switch between targets, contrary to some previous claims (Chun & Potter, 1995; Potter et al. 1998; Visser et al. 1999).

3.6.1 Perceptual and attentional factors

The idea of masking has received little consideration within the, admittedly small, AAB literature. The general view is that +1 items are required to demonstrate the AAB (Tremblay et al. 2005). From Experiment 1, this would seem to be the case. Comparing the distractor absent versus distractor present conditions clearly shows that distractors are required to elicit the AAB. However, the notion that distractor items are required to mask the targets is not conclusive. From experiment 2, the use of random distractors removes the AAB (in comparison with the changing distractor condition) and performance is similar to the no distractor condition of Experiment 1. This suggests that merely the presence of both +1 items is not sufficient to elicit the AAB, which may suggest that it is the acoustic properties of the distractor items that defines the masking potential

The explanation for the findings from Experiment 1 - that the AAB was due to the position of T2 within the changing distractor sequence - gains support from Experiment 3. T2, when occurring within a 3-item sequence, appears harder when the participants have been exposed to two cycles of the sequence, the creation of a context. With a certain level of exposure, six items in this case, the perceptual information is ordered externally, in favour of the three-item unit, rather than internally towards the separate distractor items. In addition, the dual-task demands increase the difficulty of target extraction when T2 is within the three-item unit. This combination is highlighted by the increased performance at lag 1 (Exps 1, 2 & 3) and lag 4 (Exp 1) in which T2 occurs outside the three-item unit whilst still imposing dual-task requirements. When T2 is presented at lag 9, it is in the same position within the three-item unit as at lag 2. The demands placed upon the attentional system have changed, however. This change, demonstrated by the increased performance at lag 9 for the divided attention condition, may represent the decrease of the dual-task cost

(T1 and T2 separated by 1035 ms). In addition, the association between the distractors has changed from an external grouping to an internal grouping thereby increasing the association between similar items- the formation of sub-streams (Bregman, 1990).

The amount of exposure to a sequence determines ones ability to segregate and the tendency for stream segregation to occur builds up over a period of seconds (Carlyon, Cusack, Foxton & Robertson, 2001). This transference from unstreamed to streamed is demonstrated by the repetition of a galloping ABA-ABA-ABA sequence (van Noorden, 1975). Initially all that can be heard is the galloping but after a certain amount of exposure the A and B split into two separate streams and the galloping can no longer be heard (Carlyon, et al., 2001). This process has been ascribed to primitive streaming: streaming is more likely to occur the faster the presentation rate. However, the paradigm utilised in this empirical series requires the identification of target information within the sequence. Therefore, the target information may be liable to increased interference during early exposure to the sequence, reflected in reduced performance accuracy at lag 2.

One major issue for the current series of experiments, however, is the very high level of performance across the sample population. A high proportion of participants were not included in the analyses reported above. Within these experiments, approximately 50% of participants made more than 92% of T2 judgments correctly (see General Methods for explanation and further comment). That is, a large proportion of participants performed at ceiling across experiments. Previous studies have mentioned that a certain criterion was imposed upon the selection of performance data based on theoretical considerations (Arnell & Jolicoeur, 1999; Arnell & Larson, 2002). Additionally, other researchers (Tremblay, personal communication) have encountered similar issues. However, even with the removal of a large proportion of participants, a relatively consistent pattern of AAB data has been demonstrated using parameters that are very similar to those that have been employed in some other previous work. The purpose of the next empirical series was to moderate the parameters of the paradigm in order to reduce exclusion rates in order to reduce concerns that the results reported above come about because of a selection artefacts.

Chapter 4

Empirical Series 2: Establishing the parameters of the AAB

4.1 Abstract

The previous series demonstrated the existence of the AAB under certain conditions with a reasonable degree of consistency, although the designs gave rise to a high rate of exclusion. Previous AB research suggests that an increased presentation rate can reduce T2 accuracy (Arnell, 2001; Arnell & Jolicoeur, 1999). The purpose of the present empirical series is to increase the participant inclusion rate. Increasing the stimulus presentation rate (SPR) from 7.69 items/s to 8.96 items/s had the effect of reducing the exclusion rates, allowing replications of both Experiment 1 (Experiment 4) and Experiment 3 (Experiment 5). Increasing the percentage of participants included allows the findings in these experiments to be generalised with greater confidence.

4.2 Introduction

From the previous series of experiments, several consistent findings arose. The first was that across the three experiments more than half of the sample population performed at ceiling for T2 identification. With the exclusion of those participants, the AAB was observed under a certain set of conditions. The second was that the AAB required a changing distractor context and that context needed to be initiated with at least four pre-T1 items. The latter finding is important because it emphasises for the AAB the relevance of factors influencing capacity limitations before T1 identification. This is in direct contrast to the typical view of the visual AB, where masking loads the system after the selection of the targets.

The series described below demonstrates that similar results can be obtained when the number of participants performing at ceiling is reduced markedly, thereby addressing concerns about whether the findings described above may be due to individual differences.

4.2.1 Rate of stimulus presentation

The question of stimulus presentation rate (SPR) was raised in response to the claims from Potter et al. (1998) that the AB was specific to the visual domain (Arnell and Jolicoeur, 1999). It has been suggested that the temporal resolution of the auditory system is higher than that of the visual system (Eddins & Green, 1995). Therefore, the rate of presentation may have to be higher for an auditory RAP. Potter et al. (1995, 1999) examined auditory and visual cross and within modality ABs. The SPR they used was 7.41 items/s, the slowest of the cross-modal studies, and demonstrated an AB deficit for the within-visual modality condition only. Shulman and Hsieh (1995) reported a small AB effect for the auditory within condition utilising a slightly increased SPR of 7.94 items/s. Arnell and Jolicoeur (1995, 1999), on the other hand, reported both within and cross-modal ABs with an SPR of 10.72 items/s. This suggests that the rate of presentation has more than a coincidental relationship with the AAB.

The two experiments described below were designed in order to reduce the number of participants for which the task proved to be too easy. Increasing the difficulty of the task may also render performance more sensitive to key experimental manipulations. Reducing the exclusion rate will also allow firmer conclusions to be drawn about cognitive processes that may be generalised to the population with a greater degree of confidence than those described in the previous series.

4.3 Experiment 4

4.3.1 Introduction

The aim of the present experiment was to replicate the findings of Experiment 1. Based on the findings in the previous experiments, one would assume that with changing distractors and six pre-T1 items an AAB will be evident. However, predictions for the repeated distractor condition are more equivocal. In Experiment 1, an AAB was evident for this condition but not reliable statistically. There was no evidence for an AAB for this condition in Experiment 2.The present experiment is a replication of Experiment 1 with an increased SPR of 8.69 items/s, which should provide, in a design with more experimental power, some indications as to the circumstances under which an AAB does or does not occur for repeated distractors.

4.3.2 Method

4.3.2.1 Participants

19 (13 female) volunteers, age range from 19 to 25 (mean = 20.8) were recruited from Cardiff University; participation was in exchange for a small honorarium. Five participants were excluded from the analysis due to achieving or exceeding the pre-set ceiling criterion.

4.3.2.2 Materials

As Experiment 1, although all auditory item were 115 ms in length.

4.3.2.3 Experimental design

As Experiment 1.

4.3.2.4 Procedure

See General Method.

4.3.3 Results

Figure 4.1 shows the overall probability of correct T2 identification collapsed across distractor conditions for both attention regimes. The performance curve looks very different to that of Experiment 1 (see Fig. 3.1), although performance at lag 1 for the divided attention condition is generally decreased.

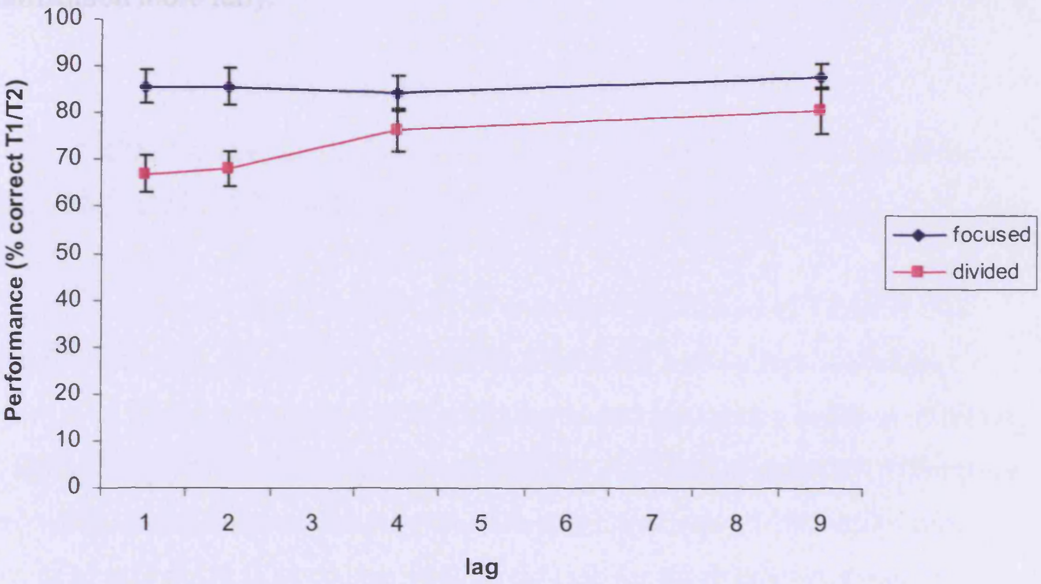

Figure 4.1: Overall performance collapsed across distractor types with SPR of 8.69 items/s (error bars = +/- 1 mean standard error)

T1 performance: T1 was reported correctly on 92% of trials in the divided attention condition. A repeated-measures ANOVA with distractor type (3 levels) and SOA (3 levels) was carried out on T1 performance revealing a significant main effect for SOA $F(3,48) = 4.652$, $mse = 32.313$, $p < .01$. The main effect arose from the likelihood of correctly identifying T1 was lower when T2 was at lag 2 (M = 90.314 S.E. = 2.494) than at lag 1 (M = 92.319 S.E. = 2.376), lag 4 (M = 94.363 S.E. = 1.873) and lag 9 (M = 91.422 S.E. = 2.462). Non-significant main effects were shown for distractor type and the subsequent interaction (p >.05), suggesting that the context does not directly affect T1 performance. SOA had an effect upon T1 performance, particular in relation to the different types of distractors. This differs from the results of Experiment 1, in which no significant relationship between conditions and T1 performance was seen.

T2 performance: The initial repeated measures ANOVA revealed a significant main effect of condition $F(1,16) = 17.562$, $mse = .205$, $p < .005$, distractor type $F(1.317,21.073) = 13.110$, $mse = .004$, $p < .005$ and SOA $F(2.331,37.302) = 6.822$, $mse = .004$ $p < .005$. These effects were moderated by significant interactions between attention and SOA $F(3,48) = 5.234$, $mse = .179$ $p < .005$, as well as the interaction between all three factors $F(5.789,92.765) = 2.205$, $mse = .931$ $p < .05$. Further analysis was carried out to understand the degree of influence exerted by the context upon T2 identification more fully.

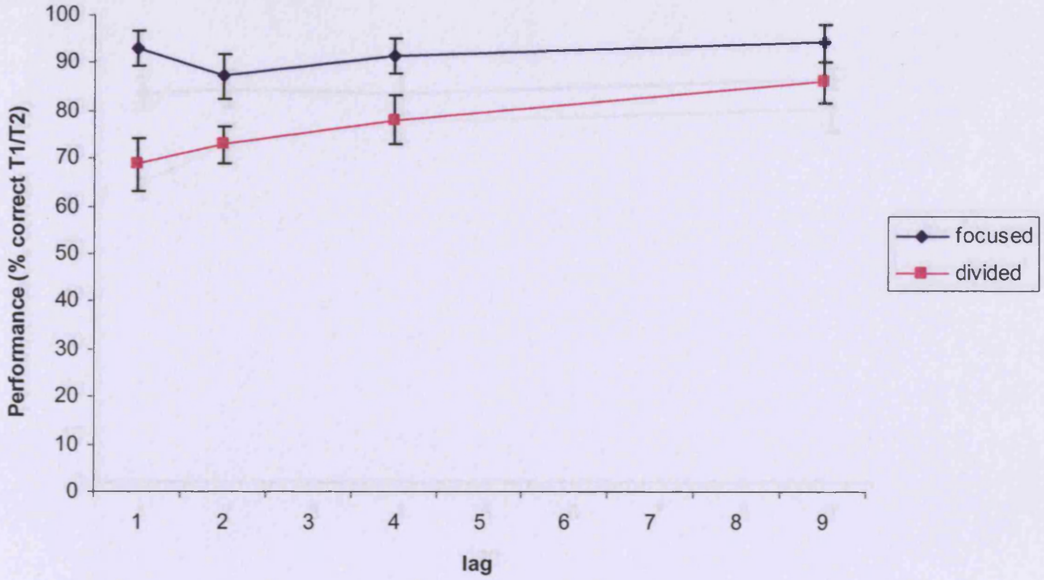

Figure 4.2: Performance for the two attention conditions with no distractor items (error bars = +1/-1 mean standard error)

Figure 4.2 shows the probability of correct identification of T2 for the no distractor condition. An ANOVA revealed a significant main effect of attention $F(1,16) = 13.861$, $mse = .006$ $p < .005$ and a significant interaction between attention and SOA $F(2.378,38.043) = 3.341$, $mse = .004$, $p < .05$. Similar statistical differences were demonstrated between the same condition in Experiment 1- the interaction between attention and SOA- demonstrating the task for the divided attention condition is more easily achieved as the number of items intervening the two targets is increased.

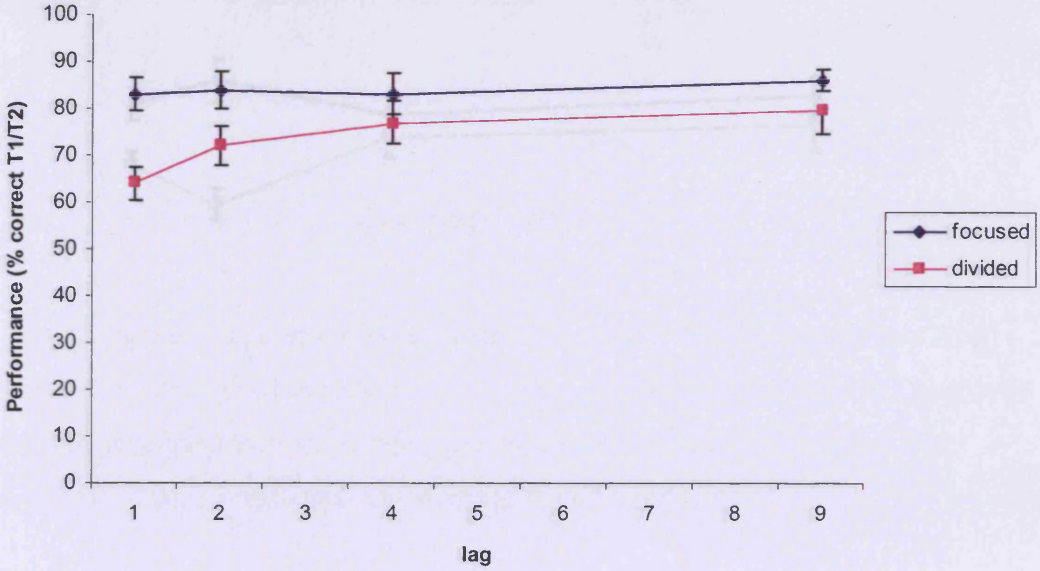

Figure 4.3: Performance for the two attention conditions with repeated distractor items (error bars = +1/-1 mean standard error)

The same analysis was carried out on the repeated distractor condition (see Fig. 4.3), revealing only significant main effects for attention $F(1,16) = 9.576$, $mse = .009$ $p < .01$ and SOA $F(2.808,44.933) = 3.962$, $mse = .002$ $p < .02$. This reflects the fact that performance increases with SOA and was greater in the focused compared to the divided condition.

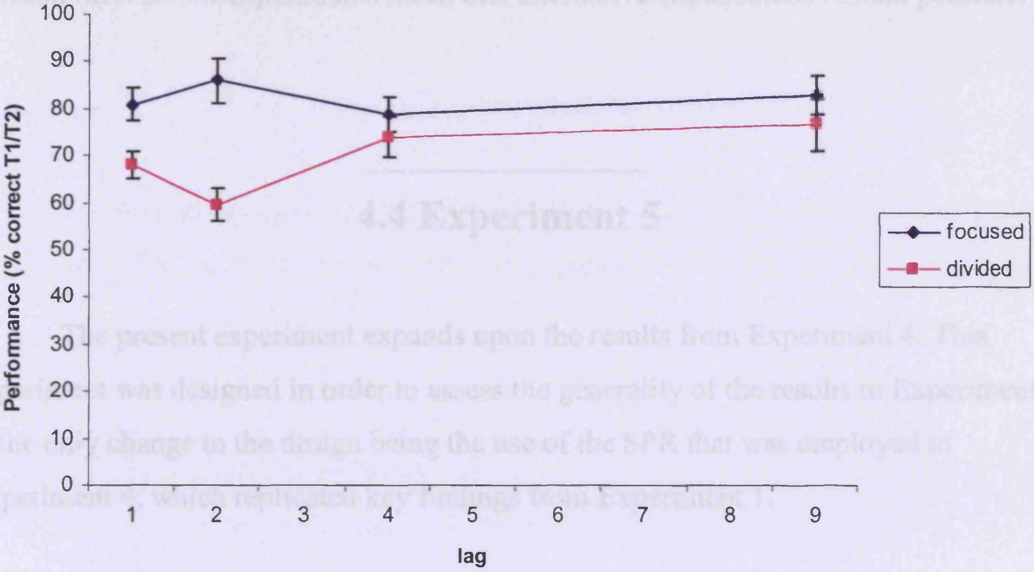

Figure 4.4: Performance for the two attention conditions with changing distractor items (error bars = +1/-1 mean standard error)

The analysis for the changing distractor condition (Fig. 4.4) demonstrated significant main effects for both attention $F(1,16) = 23.065$, *mse* = .006 $p< .001$ and SOA $F(2.283,36.530) = 5.714$, *mse* = .003 $p< .01$. The interaction between attention and SOA was significant $F(3.934,46.947) = 5.282$, *mse* = .001 $p< .005$. To investigate lag 1 sparing, a planned comparison was carried out on the difference between performance at lag 1 and lag 2 across attention conditions (M = -13.603, SD = 17.432) $t(16) = 3.217$, $p< .01$.

In summary, the three-way interaction arising from the initial analysis occurs because the AAB was obtained in the changing distractor condition only.

4.3.4 Discussion

The initial finding from the present experiment replicates the findings from Experiment 1 with a markedly reduced participant exclusion rate. The results suggest that the repeated distractor condition is not typically associated with the AAB, as the effect was not present in the current experiment despite superior statistical power in comparison to Experiment 1, although the different SPRs and consequently participant attrition rates across experiments mean that alternative explanations remain possible.

4.4 Experiment 5

The present experiment expands upon the results from Experiment 4. This experiment was designed in order to assess the generality of the results in Experiment 3, the only change to the design being the use of the SPR that was employed in Experiment 4, which replicated key findings from Experiment 1.

4.4.1 Method

4.4.1.1 Participants

20 (13 female) volunteers aged between 18 and 23 (mean age = 19.7) were recruited from Cardiff University; their participation was in exchange for a small honorarium. Four participant's data were excluded from the resulting analysis as their performance met or exceeded the exclusion criterion (see General Methods for explanation).

4.4.1.2 Materials

As Experiment 3, with changing distractor only but each stimulus was 115ms in length. As with Experiment 3, the number of pre-T1 items defined the conditions; zero, three or six distractor items preceded T1.

4.4.1.3 Experimental design

The three repeated measures were, attention (focused vs. divided), T1-T2 SOA, (which corresponds to lags 1, 2 and 9) and pre-T1 lead in (0 items, 3 items or 6 items). Each participant completed focused and divided conditions. The experiment consisted of 72 trials for both the focused attention (3 blocks) and divided attention (3 blocks) conditions, creating 432 trials in total.

4.4.1.4 Procedure

See General method.

4.4.2 Results

The probability of the correct identification of T2 collapsed across number of pre-T1 items for both attention conditions is illustrated in Figure 4.5.

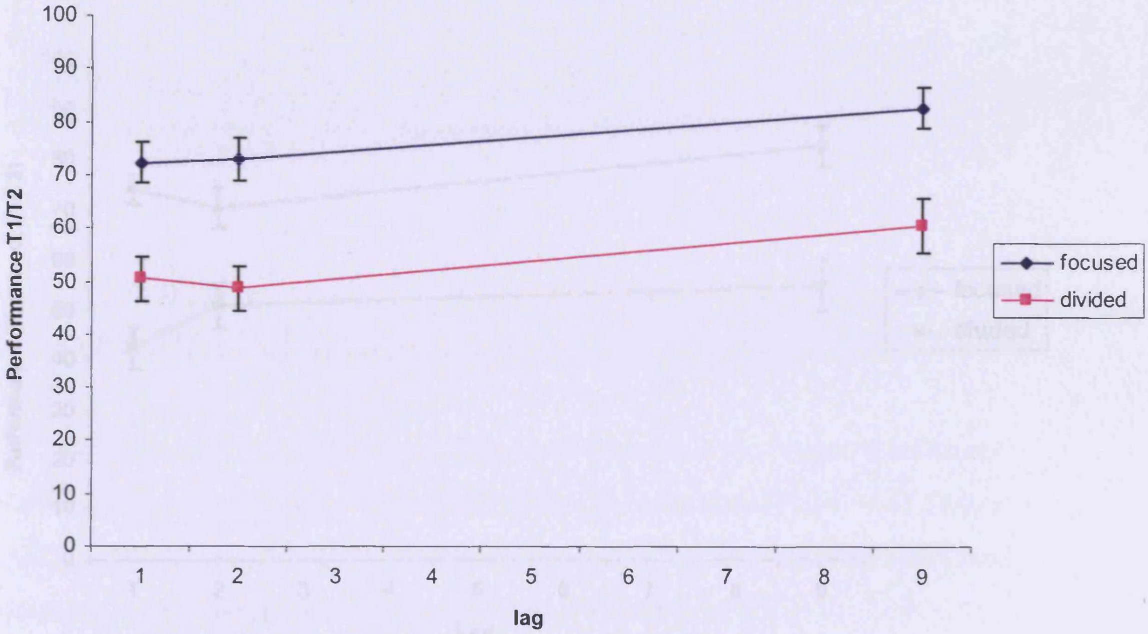

Figure 4.5: Overall performance collapsed across pre-T1 conditions with SPR of 8.69 items/s (error bars = +/- 1 mean standard error)

T1 performance: On average, T1 was reported as correct on 78.2% of trials during the divided attention condition. A repeated measures ANOVA with number of pre-T1 items (3 levels), and SOA (3 levels) was carried out on T1 performance and revealed no significant main effects or interactions ($p > 0.5$). This demonstrates that T1 performance was not affected by SOA or number of pre-T1 items. The increase in SPR seems to eliminate performance differences across pre-T1 conditions, as compared with Experiment 3.

T2 performance: Performance for the correct identification of T2 for all pre-T1 items was submitted to a repeated measures ANOVA. The analysis revealed significant main effects for attention $F(1,15) = 722.730$, $mse = .179$, $p < .001$ and SOA $F(2,30) = 10.344$, $mse = .112$, $p < .001$ only. These effects were moderated by significant interactions between attention and number of pre-T1 items $F(1.493,22.399) = 4.052$, $mse = .005$, $p < .05$ and the interaction between all three factors $F(2.265,40.321) = 4.917$, $mse = .005$, $p < .01$. To understand the influence of the number of pre-T1 items separate analyses was carried out upon the data for each condition.

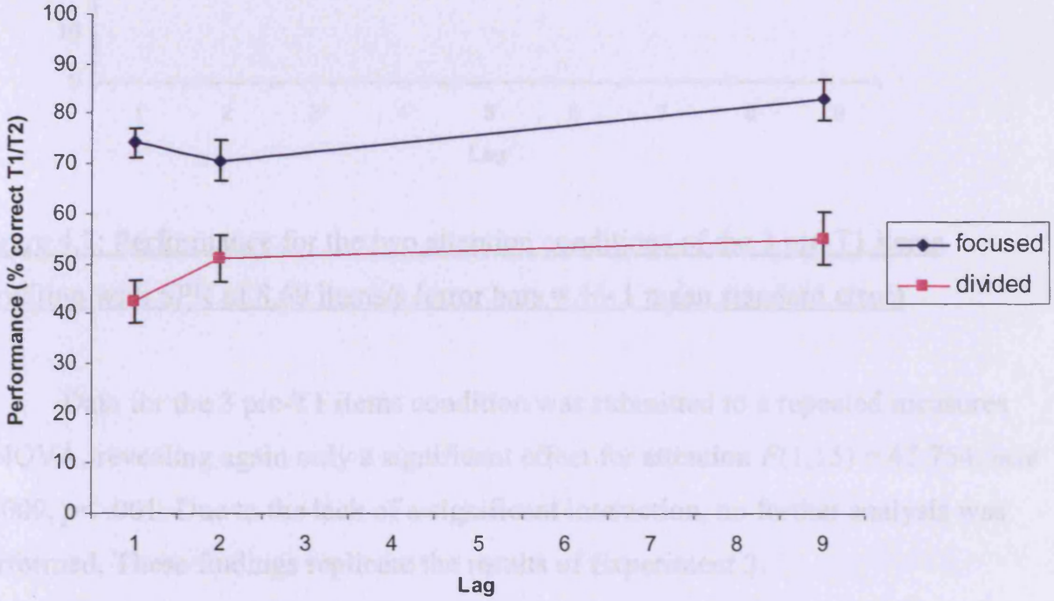

Figure 4.6: Performance for the two attention conditions of the 0 pre-T1 items condition with SPR of 8.69 items/s (error bars = +/- 1 mean standard error)

Figure 4.6 shows the likelihood of correct T2 identification with 0 pre-T1 items. An ANOVA revealed only a significant main effect for attention $F(1,15) = 49.075$, $mse = .128$, $p < .001$. From the statistical outcome, all that can be surmised is that performance across attention conditions is different, and from Figure 4.6 one may assume that the task of correctly identifying T1 and T2 is more difficult than identifying T1 alone.

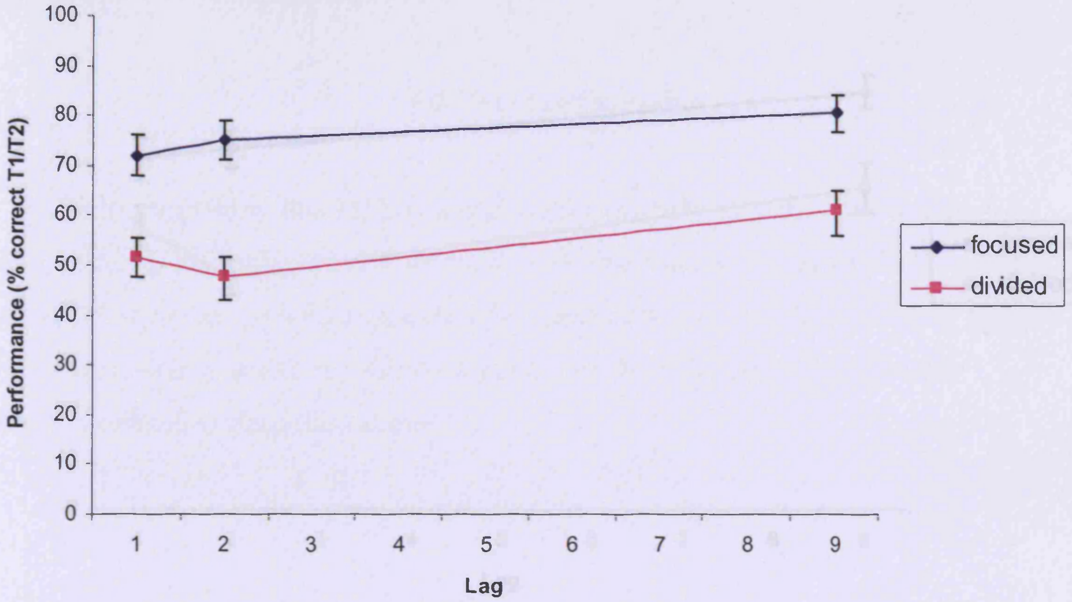

Figure 4.7: Performance for the two attention conditions of the 3 pre-T1 items condition with SPR of 8.69 items/s (error bars = +/- 1 mean standard error)

Data for the 3 pre-T1 items condition was submitted to a repeated measures ANOVA, revealing again only a significant effect for attention $F(1,15) = 45.754$, *mse* = .009, $p < .001$. Due to the lack of a significant interaction, no further analysis was performed. These findings replicate the results of Experiment 3.

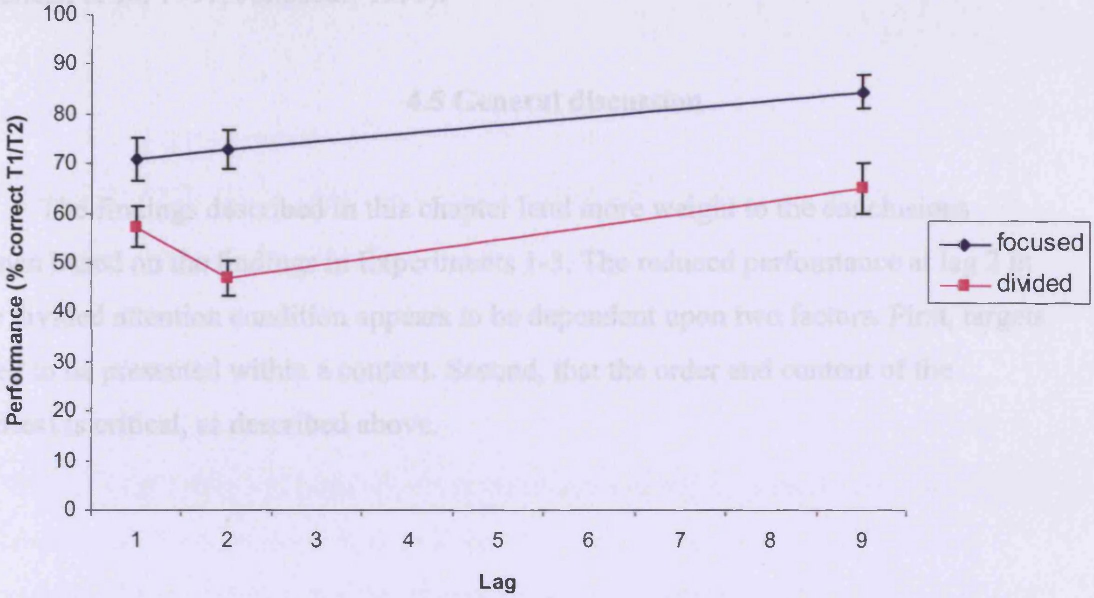

Figure 4.8: Performance for the two attention conditions of the 6 pre-T1 items condition with SPR of 8.69 items/s (error bars = +/- 1 mean standard error)

Data from the 6 pre-T1 item condition (see Fig. 4.8) was submitted to an ANOVA revealing significant main effects for both attention $F(1,15) = 67.704$, $mse = .004$, $p < .001$ and SOA $F(1.451,21.771) = 13.823$, $mse = .005$, $p < .001$ as well as a significant interaction between attention and SOA $F(2,30) = 4.202$, $mse = .002$, $p = .025$. The interaction reflects the fact that the performance decrement at lag 2 in the divided attention condition is larger than at the other lags. A planned comparison to verify the existence of lag 1 sparing demonstrated the performance decrement at lag 2 was larger than at lag 1 ($M = -38.056$, $SD = 26.652$), $t(15) = -5.711$ $p < .001$.

4.4.3 Discussion

These data replicate the findings from Experiment 3; a T1-T2 SOA interaction was obtained only with six pre-T1 items. In addition, the presence of lag 1 sparing suggests that an AB was obtained. Since 65% of participants were excluded from Experiment 3, and this was not the case for the present study, these data suggest that the findings generalise to a greater extent than could be inferred based on the findings in Experiment 3. The exclusion rate here was c.20%, a rate similar to that in some visual AB studies (Raymond et al., 1992, 1994) as well as some auditory AB studies (Duncan et al., 1997; Jolicoeur, 1999).

4.5 General discussion

The findings described in this chapter lend more weight to the conclusions drawn based on the findings in Experiments 1-3. The reduced performance at lag 2 in the divided attention condition appears to be dependent upon two factors. First, targets need to be presented within a context. Second, that the order and content of the context is critical, as described above.

Chapter 5

Empirical Series 3: Sources of perceptual and attentional interference and the AAB

5.1 Abstract

The AAB effect has been shown to be reliant upon the interaction of non-target information and the imposed dual-task cost. In terms of the principles of auditory perception, the explanation for this is that the acoustic properties of the distractors, coupled with their method of presentation, mean that the perceptual system will group them together. The process of grouping is also defined in the visual domain via the Gestalt principle of exclusive allocation (see Fig, 1.9: Rubin's face/vase diagram). A great deal of investigation has been undertaken concerning the role of perceptual interference for the visual AB, centring on the role played by masking. The previous empirical work in this thesis is consistent with the view that the promotion of distractors into streams due to their similarity alters the masking potential of the + 1 items. In the present series of experiments, the focus turns to the perceptual relationship between targets and distractors. To summarise the findings: increasing exposure to pre-T1 beyond the levels in Experiment 5 eliminated the AAB (Experiment 6). In addition, increasing exposure to target items by increasing the amount of practice also eliminated the AAB (Experiments 7A & 7B). Presenting the practice targets in a context, however (Experiment 7B), reduced the AAB to a greater extent than if practice targets were presented without a context (Experiment 7A). An AAB was evident when targets were presented within a stream of semantically similar distractors (Experiments 8A & 8B). Switching the semantic category between targets and distractors, meanwhile, eliminated the AAB (Experiment 8C). These results for the most part mirror those for the visual AB and highlight important correspondences across the two modalities.

5.2 Introduction

The purpose of the experiments described in this section was to continue the investigation of antecedents of the AAB by looking at the influence of additional perceptual factors, in order to assess further the adequacy of streaming and masking accounts as applied to the AAB. The perceptual factors related to the initial extraction of information rather than the subsequent postperceptual processing. As shown earlier (Experiments 1, 2 & 4), changes within the context have produced variation in the likelihood of target identification. By reducing the number of pre-T1 items in the changing distractor condition to 3 items or less, the AAB was eliminated. The AAB was evident, however, when 6 items (2 cycles of distractors) were presented. If the AAB in this case results from a decreased ability to extract the relevant information from the auditory scene due to the binding of the three-item distractor unit, changing the strength of that bond will reduce the AAB effect, as noted in section 5. The bond may be affected in two ways; first, by increasing exposure to the distractor items, and second, by increasing the amount of exposure the participant has to the target items before the test phase. Increasing the exposure to pre-T1 items should increase the likelihood that sub-streams that are more coherent are formed out of the three-item sequence. Therefore, the impact upon the AAB should be to attenuate the lag 2 decrement due to the weakening of the three-item bond in favour of separate distractor unit sub-streams. Increasing exposure to the targets through increased practice may strengthen the mental representation of the target, thereby allowing more accurate target information extraction, again acting to attenuate the AAB.

The potential influence of semantic or categorical differences between targets and distractors was investigated in Experiment s 8A, 8B and 8C. Considerable work has been carried out on the role of semantic information and the visual AB (Chun & Potter, 1995; Maki et al., 1999; Raymond et al 1994). The principal finding is that similarity in meaning, rather than featural make-up, influences the visual AB. Therefore, the explanation of the visual AB likely involves competition for limited postperceptual resources that process semantic information. In keeping with this finding, fMRI studies have revealed activation within the posterior-parietal cortex (intraparietal sulcus) and lateral frontal cortex during the processing of T2 in visual AB tasks (Gross, Schmitz, Schnitzler, et al 2004; Marois, Chun & Gore, 2000). This activation is thought to relate to an attempt to select from competing meaningful representations at a postperceptual level (Marois et al., 2000). At issue here is whether, at the behavioural level, this is also true for the AAB.

5.3 Experiment 6

The aim of the present experiment was to examine more closely the findings from Experiment 4. As proposed in Chapter 1, and shown in Experiments 3 and 4, the number the pre-T1 items affects whether an AAB occurs. The previous experiments in general demonstrated the influence of the context in which the targets are presented. The findings in these experiments are consistent with the view that the binding of the changing distractors into a single unit creates the AAB and the presentation of targets within this unit reduces performance at lag 2 (see also Chapter 3). According to this account, the lack of performance decrement at lags 1 and 4 is due to their position at the beginning of the distractor sequence. However, the perceptual binding account cannot fully account for the pattern of data. With T2 at lag 2 and with six pre-T1 items, eight items have occurred before T2. This is the same amount as when T2 is presented at lag 9 with zero pre-T1 items. Additionally, in both conditions T2 is presented in the same position within the three-distractor sequence. Therefore, one may surmise that the performance decrement at lag 2 within the divided attention condition arises from a combination of T2's position within the distractor sequence and the additional processing of T1.

The previous experiment demonstrated that the presentation of three pre-T1 items was insufficient to produce the AAB. In order to examine further of the relationship between perceptual binding and exposure, in the present study the number of pre-T1 items was increased. Streaming theory suggests that the formation of sub-streams from a sequence is more likely to occur the more the sequence is repeated (Bregman, 1990; Warren 1982). By increasing the number of pre-T1 items, therefore, the likelihood that sub-streams that are more coherent are formed increases, which should make the extraction of target information easier and result in attenuation of the AAB.

5.3.2 Method

5.3.2.1 Participants

27 (13 female) volunteers, age range 19 to 24 (mean = 20.1) were recruited from Cardiff University; participation was exchanged for a small honorarium. Four participants were excluded from the analysis as they exceeded the pre-set ceiling criterion (see Chapter 2).

5.3.2.2 Materials

Each trial of the RAP comprised auditory samples, all 115 ms in length, and contained either 'Cod' or Cot', and 'Nab' or 'Nap' targets. The order of target presentation was always fixed, e.g. if T1 was either 'Cod' or Cot', T2 would always be either 'Nab' or 'Nap' and vice versa. Only the changing distractor was used. T2 was presented after T1 at four SOAs; adjacent at 115 ms (lag 1), 230 ms (lag 2), 460 ms (lag 4) and 920 ms (lag 9). Timings for the T1-T2 SOA for the no distractor condition remained constant with the addition of silent periods.

5.3.2.3 Experimental design

The three repeated measures were; condition (focused vs. divided attention), T1-T2 SOA, (which correspond to lags 1, 2, 4 and 9) and pre-T1 lead in (0 items, 9 items or 18 items). Each participant completed focused and divided conditions. The experiment consisted of 96 trials for both the focused attention (3 blocks) and divided attention (3 blocks) conditions. There were 576 trials in total with a short break between each block.

5.3.2.4 Procedure

See General Method.

5.3.3 Results

Figure 5.1 shows the probability for the correct identification of T2 collapsed across numbers of pre-T1 items for both attention conditions.

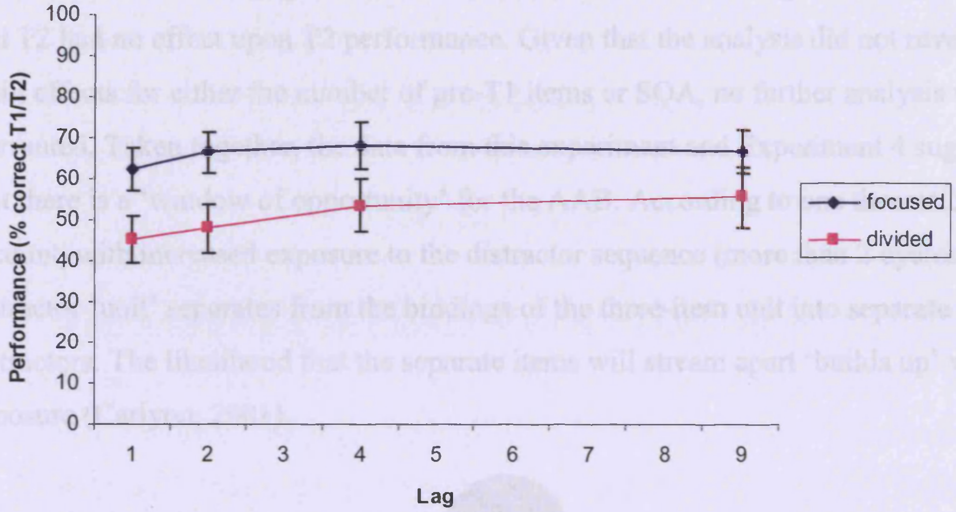

Figure 5.1: Overall performance for the two attention conditions combined across number of pre-T1 items (error bars = +1/-1 mean standard error)

T1 performance: T1 was reported correctly on 64.5% of trials. Data was submitted to a repeated-measures ANOVA with factors of attention (2 levels), lead in (3 levels) and SOA (4 levels) and revealed no significant effects.

T2 performance: The initial repeated-measures ANOVA revealed only a significant main effect of attention $F(1,22) = 23.934$, $mse = .916$ $p < .001$ (all other p's $> .15$). Due to the lack of interactions between the factors, no further analyses were conducted (see appendix 2 for breakdown of data separated according to lead-in).

5.3.4 Discussion

The data demonstrated that the task for T2 was more difficult when identification of T1 was required as well, compared to identifying T2 alone. The number of items occurring before T1 or the number of intervening items between T1 and T2 had no effect upon T2 performance. Given that the analysis did not reveal any main effects for either the number of pre-T1 items or SOA, no further analysis was warranted. Taken together, the data from this experiment and Experiment 4 suggests that there is a 'window of opportunity' for the AAB. According to one theoretical account, with increased exposure to the distractor sequence (more than 2 cycles), the distractor 'unit' separates from the bindings of the three-item unit into separate distractors. The likelihood that the separate items will stream apart 'builds up' with exposure (Carlyon, 2001).

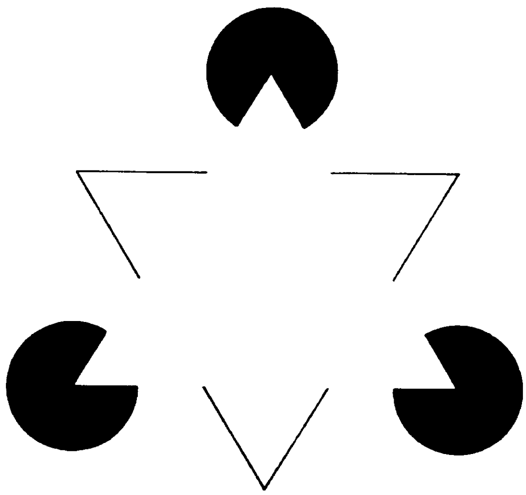

Figure 5.2: The Kanizsa triangle (1955)

The allocation of the distractors into streams forms a more stable context that in turn allows the segregation of items into separate events. The ordering of the context permits greater allocation of resources towards each item due to the reduced load whereby extraction of meaning is easier for one, rather than three items. This can be illustrated with the Kanizsa triangle (Kanizsa, 1955, see Fig 5.2) where by the nature of the context guides meaning. This suggests that the perceptual influence of exposure to the distractors affects performance by reducing the restriction upon resource allocation thus freeing up attentional processes. Therefore, increasing exposure to distractor items attenuates the AAB, presumably because of changes in how the distractors are represented. In the next experiment, the effect of increasing exposure to targets is investigated.

5.4 Experiment 7A

5.4.1 Introduction

If the AAB is due to the difficulty of extracting target information from perceptual units, then increased exposure to the target may reduce the AAB. The influence of the pre-T1 items has been shown to influence performance accuracy for T2. Experiment 5 demonstrated that with zero or three pre-T1 items performance at lag 2 for the divided attention condition does not differ from that of lag 1, but with six pre-T1 items, an AAB is evident. The present experiment seeks to understand the influence of practice upon target extraction. The role of practice is something that has received no discussion in the visual AB literature. In everyday life, practice, across a range of skills, both physical and mental, can lead not only to improvements in performance, but also to the abilities becoming relatively more automated, requiring less conscious monitoring for completion. Indeed, after skills have become automated, performance can in some circumstances deteriorate when conscious attempts to guide performance are engaged. The assumption in the visual AB literature is that investigations of the AB are explorations of a relatively fixed capacity limitation. No experiments have, however, addressed this issue directly.

During the practice phase, the targets will be presented on their own: the no distractor condition. From a streaming perspective, with an increase in target exposure the extraction of target information subsequently should become easier and a smaller AAB should be observed. If the AAB, however, is a general consequence of a relatively fixed resource bottleneck, then practice will not influence the AAB.

5.4.2 Method

5.4.2.1 Participants

20 (11 female) volunteers, age range from 19 to 23 (mean = 19.9) were recruited from Cardiff University; participation was exchanged for a small honorarium. Four participants were excluded from the analysis as their performance exceeded the pre-defined ceiling level criterion (see General methods).

5.4.2.2 Materials

Each trial of the RAP comprised auditory samples, all 115 ms in length, and contained either 'Cod' or Cot', and 'Nab' or 'Nap' targets. The order of target presentation was always fixed, e.g. if T1 was either 'Cod' or Cot', T2 would always be either 'Nab' or 'Nap' and vice versa. Distractor sequences and T1-T2 SOAs were the same as Experiment 1. Six distractor items always preceded T1. Timings for the T1-T2 SOA for the no distractor condition were held constant by the addition of silent periods.

5.4.2.3 Experimental design

The three repeated measures were; condition (focused vs. divided attention), T1-T2 SOA, (which correspond to lags 1, 2, 4 and 9) and distractor type (no distractor, repeated distractor and changing distractor). Each participant completed focused and divided conditions. The experiment consisted of 96 trials for both the focused attention (3 blocks) and divided attention (3 blocks) conditions. There were 576 trials in total with a short break between each block. Each participant completed an extended practice session comprising 48 practice trials containing only the targets (sequences from the no distractor condition in Experiment 1 & 4).

5.4.2.4 Procedure

See General Method.

5.4.3 Results

The probability of the correct identification of T2 for both attention conditions and collapsed across distractor types is shown in Fig. 5.3.

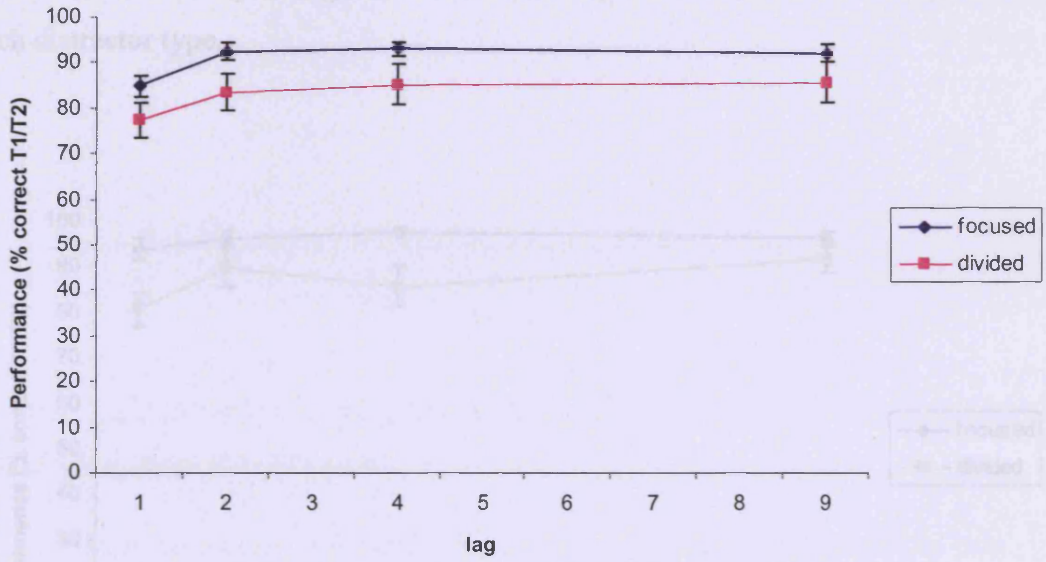

Figure 5.3: Overall performance for attention conditions combined across distractor types (error bars = +1/-1 mean standard error)

T1 performance: On average, T1 was reported correctly on 91.276% of trials. T1 Performance data was submitted to a 2-way repeated measures ANOVA and revealed a significant main effect for distractor type $F(2,30) = 3.959$, $mse = 28.845$, $p < .030$ and SOA $F(3,45) = 5.072$, $mse = 24.603$, $p < .005$. These effects were moderated by a significant interaction between the two factors $F(6,90) = 2.888$, $mse = 20.003$, $p < .02$. The results from this analysis suggest that performance for T1 is susceptible to the context provided by the distractor and the number of intervening items between T1 and T2. This replicates the findings from Experiment 5A suggesting that with the present SPR, distractor type affects T1 performance as well as performance for T2, unlike Experiment 1 where a slower SPR was employed. In comparison, the previous experiment that utilised the same SPR and the changing distractor showed that increased exposure to the context before T1 is presented removes all T1 dependent effects.

T2 performance: The initial repeated-measures ANOVA revealed significant main effects for attention $F(1,15) = 4.804$, $mse = .257$, $p < .05$, distractor type $F(2,30) = 17.309$, $mse = .002$, $p < .001$ and SOA $F(1.817,27.261) = 8.471$, $mse = .297$ $p < .005$. The effects were moderated by the interaction incorporating all three factors $F(4.795,71.932) = 2.859$, $mse = .001$ $p < .03$. To understand further the influence of the distractor items upon target identification, a separate analysis was carried out for each distractor type.

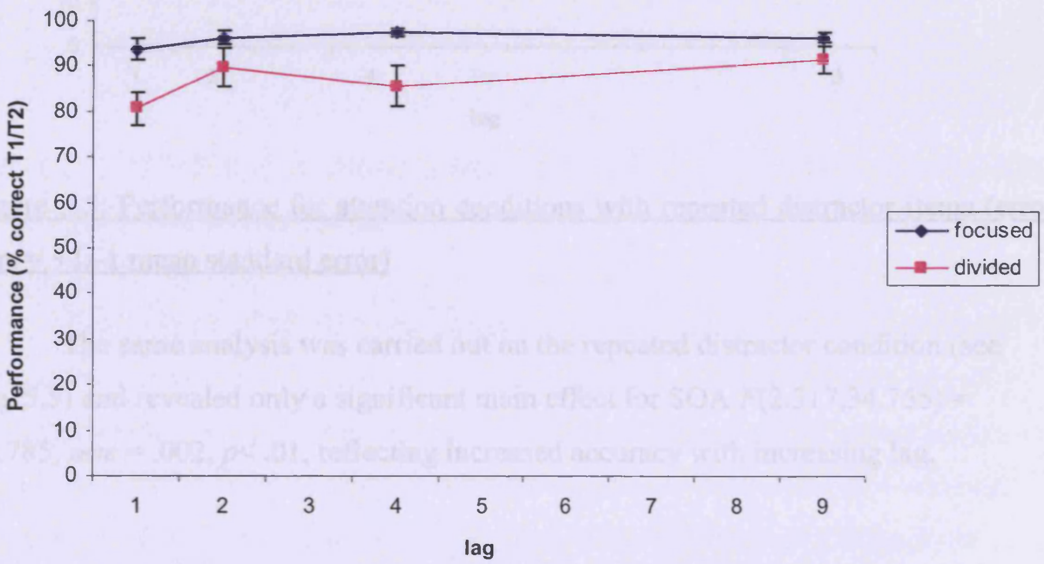

Figure 5.4: Performance for attention conditions with no distractor items (error bars = +1/-1 mean standard error)

The data for the no distractor condition (see Fig 5.4) was submitted to a repeated-measures ANOVA. The analysis revealed significant main effects of attention $F(1,15) = 5.483$, $mse = .008$, $p = .033$ and SOA $F(2.219,33.288) = 4.842$, $mse = .001$, $p < .015$, as well as a significant interaction between the two factors $F(2.150,32.247) = 5.117$, $mse = .001$, $p = .010$. The interaction may describe both the general trend of increased performance within the divided attention condition with the increase in SOA as well as the differences between attentional conditions at lags 1 and 4 only.

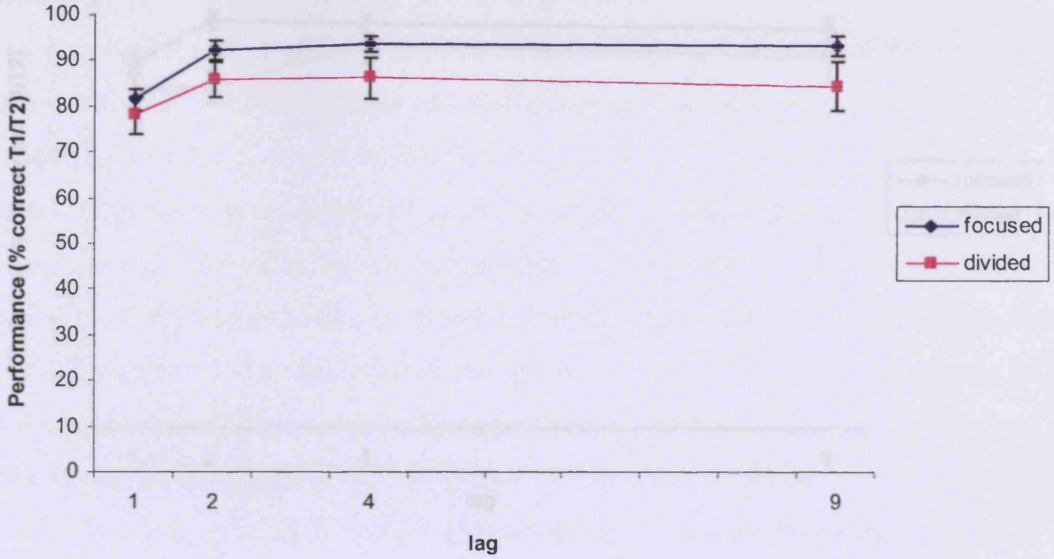

Figure 5.5: Performance for attention conditions with repeated distractor items (error bars = +1/-1 mean standard error)

The same analysis was carried out on the repeated distractor condition (see Fig. 5.5) and revealed only a significant main effect for SOA $F(2.317,34.755) = 13.785$, $mse = .002$, $p < .01$, reflecting increased accuracy with increasing lag.

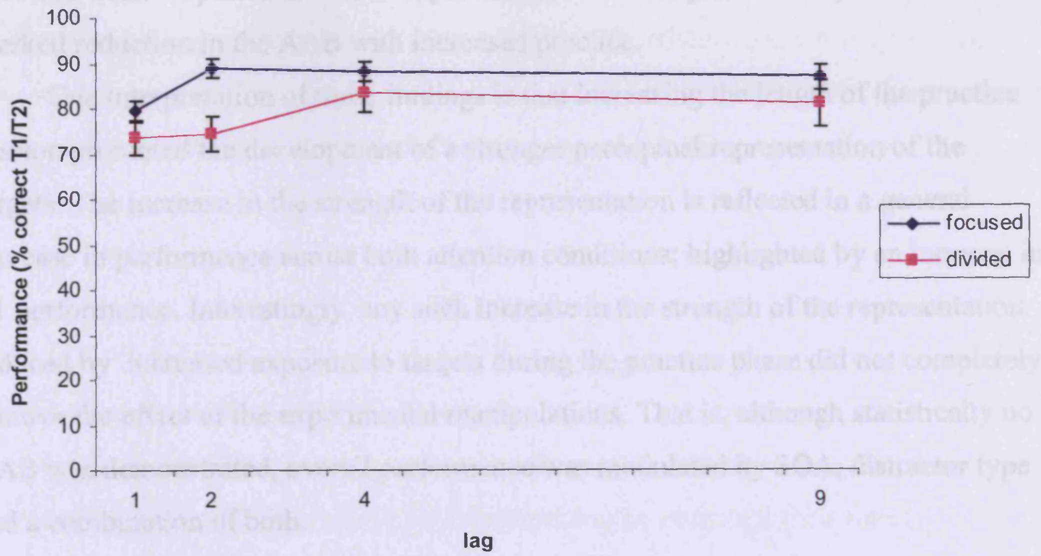

Figure 5.6: Performance for attention conditions with changing distractor items (error bars = +1/-1 mean standard error)

The analysis of the changing distractor condition revealed only a significant main effect of attention $F(1,15) = 5.275$, $mse = .008$, $p < .05$: detecting two targets leads to lower T2 accuracy than simply detecting one. Thus the AAB effect for the changing distractor condition, which has been replicated on a number of occasions, was attenuated with increased pre-test exposure to the target items. Although not supported by an interaction, a reduced AAB pattern survived, highlighted by the difference between performance at lag 1 and lag 2 across attention condition, ($M = -8.333$, $SD = 13.693$) $t(15) = -2.434$, $p < .03$.

In summary, the three-way interaction highlighted by the initial global analysis resulted primarily from the presence of an AAB in the changing condition only, although the data for the no distractor condition are somewhat difficult to account for fully.

5.4.4 Discussion

The results from the present experiment demonstrate that an increase in practice in which only targets are presented reduces the AAB. Whether this is a modality specific effect cannot be substantiated because of a lack of examination of practice effects in VAB studies to date. The changing distractor condition replicated the AAB effect reported in earlier experiments, while the present study revealed a marked reduction in the AAB with increased practice.

One interpretation of these findings is that increasing the length of the practice session promoted the development of a stronger perceptual representation of the targets. The increase in the strength of the representation is reflected in a general increase in performance across both attention conditions; highlighted by an increase in T1 performance. Interestingly, any such increase in the strength of the representation induced by increased exposure to targets during the practice phase did not completely remove the effect of the experimental manipulations. That is, although statistically no AAB was demonstrated, overall performance was modulated by SOA, distractor type and a combination of both.

Therefore, in relation to the T-D relationship, increasing the strength of the target representations does not fully eliminate the effect of the context, as distractor type still exerts an effect upon the likelihood of correct target identification. This putative increase in the strength of target representations may affect the processing of sequences in two ways. First, the masking potential of the distractors is reduced. Second, the streaming potential is affected as the targets are more easily segregated from the sequence. Both these factors would result in a reduction in SOA-related performance differences. This would suggest that the T-D relationship had not been learned effectively enough to reduce any context dependent effects, the AAB as demonstrated in the changing distractor condition.

The design of the next experiment was an attempt to generalise the findings of Experiment 7A in a paradigm where in addition to providing exposure to targets participants are exposed to a stimulus sequence (the repeated distractor condition) which shares additional commonalities with the changing distractor condition.

5.5 Experiment 7B

The present experiment expands upon the findings of the previous one, by exposing participants to a similar increased practice session, but using a repeated distractor sequence instead of presenting the targets without distractors. The previous experiment demonstrated that increased practice attenuates the AAB (for example, the size of the performance decrement across conditions at lag 2 in Exp. 4 was 26%, while in the previous experiment it was 12%). All that differed between these experiments was the presence or absence of practice phases.. The present experiment was designed in order to explore further the effect of learning on the AAB.

5.5.2 Method

5.5.2.1 Participants

16 (12 female) volunteers, age range from 19 to 29 (mean = 20.7) were recruited from Cardiff University; participation was in exchange for a small honorarium. The data from seven participants was excluded from the analysis as their performance exceeded the pre-defined ceiling level criterion (see General Methods).

5.5.2.2 Materials

As Experiment 7A.

5.5.2.3 Experimental design

As Experiment 7A, except that each participant completed 48 practice trials containing sequences from the repeated distractor condition.

5.5.2.4 Procedure

See General Method.

5.5.3 Results

Figure 5.7 shows the probability of correctly identifying T2 for both attention conditions collapsed across distractor conditions.

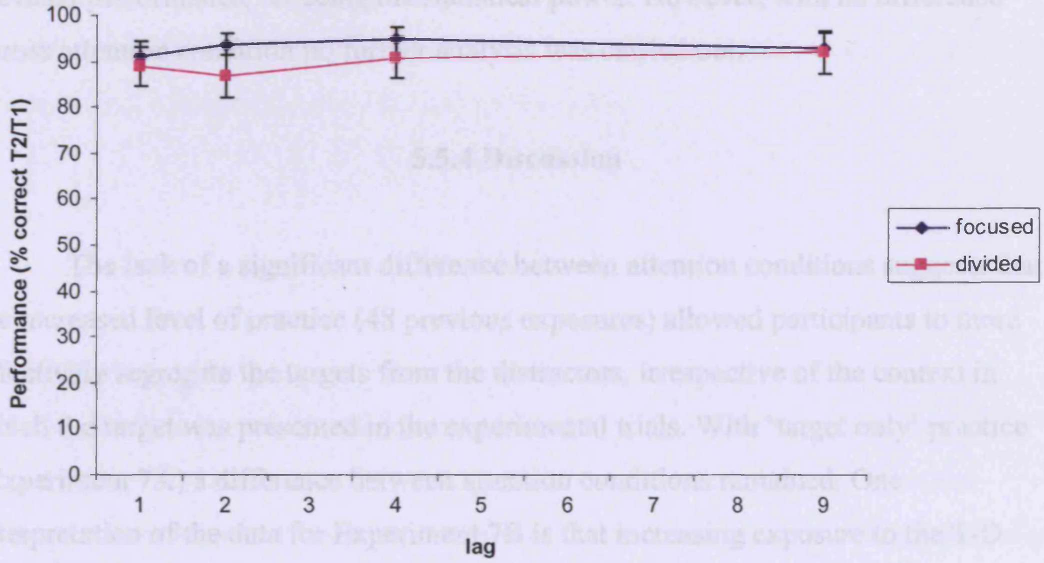

Figure 5.7: Overall performance for attention conditions combined across distractor types (error bars = +1/-1 mean standard error)

T1 performance: On average, T1 was reported as correct on 93% of trials in the divided attention condition. A 2-way repeated-measures ANOVA, distractor type (3 levels) and SOA (4 levels) was carried out on T1 performance and revealed only a significant main effect for SOA $F(3,24) = 8.075$, $mse = 23.512$, $p < .001$, reflecting the fact that the task for T1 becomes easier as the number of intervening distractors increases.

T2 performance: Performance for the correct identification of T2 was analysed via ANOVA, where the three repeated measures were attention (2 levels), distractor type (3 levels) and SOA (4 levels). The analysis revealed only significant main effects for both distractor type $F(2,16) = 9.781$, $mse = .004$, $p < .001$ and SOA $F(1.739,14.092) = 4.739$, $mse = .005$, $p < .02$. Due to the lack of a significant difference across attention conditions, further analysis is not justified. However, it may be worth highlighting the differences in overall accuracy across distractor type and SOA. Performance was reduced with distractor complexity whereby accuracy was higher in the no distractor condition than for the repeated and changing conditions with the changing distractor condition proving to be the hardest. Performance for the divided attention condition increased exponentially with SOA. One factor that may have influenced these results was the large number of participants excluded due to elevated performance, reducing the statistical power. However, with no difference across attention condition no further analysis was carried out.

5.5.4 Discussion

The lack of a significant difference between attention conditions suggests that the increased level of practice (48 previous exposures) allowed participants to more effectively segregate the targets from the distractors, irrespective of the context in which the target was presented in the experimental trials. With 'target only' practice (Experiment 7A) a difference between attention conditions remained. One interpretation of the data for Experiment 7B is that increasing exposure to the T-D relationship allows greater ease of target extraction irrespective of the any dual-task demands.

5.6 Experiments 8A-8C

The aim of the present series of experiments was to examine the notion that, as with the visual AB (Chun & Potter, 1995; Shapiro et al., 1997), the deficit arises at least in part from a restriction in resource allocation. If this account were true, then the prediction would be that a larger AAB would be shown when targets and distractors were categorically related, since they should be competing for the same resources. This prediction was tested using letter and digit stimulus sets. The distractors were either the same or different from the targets (e.g. letter targets and digit distractors or the reverse). Distractor sequences were either repeated or changing. An additional experimental factor, a tone presented concurrently with the target, was added. The rationale behind this addition arose from the work carried out by Karen Arnell (Arnell

& Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002) investigating the existence of a cross-modal AB utilising single auditory letter targets and distractors. One defining characteristic of the visual AB paradigm is that the targets are highlighted from the distractors by a change in either luminescence or colour of the target (see section 1.3.3 for discussion). The addition of a tone was intended to initiate similar demands upon processing resources by increasing awareness of the target event. Therefore, as a stimulus set similar to that of Arnell was utilised for the present series of experiments, a tone was added. In the first two experiments, the AAB associated with letters and digits alone is characterised, prior to an examination of the influence that categorical similarity has on the AAB.

5.6.1 Method

5.6.1.1 Participants

21 (13 female) volunteers, age range from 19 to 22 (mean age = 20.7) were recruited from Cardiff University; their participation was in exchange for course credit. Four participants were excluded as they met or exceeded the 'ceiling' exclusion criteria and were removed from the analysis.

5.6.1.2 Materials

All auditory samples were 100 ms in duration. Targets were either 'K', 'L', 'R' or 'Y' with target presentation order not fixed. Targets were presented with a concurrent tone. Distractor sequences comprised two separable groups; repeated (repetition of 'B') and changing (cycling 'B', 'C' and 'D').

5.6.1.3 Design

The three repeated measures were attention (focused vs. divided), SOA (130, 260, 520 & 1170 ms) and distractor type (repeated & changing), all within subjects and fully randomised. The experiment consisted of six blocks of 64 trials for the focused (3 blocks) and divided (3 blocks) conditions. There were 386 trials in total with a short break between each block. Participants alternated between focused and divided blocks, and 50% of the participants completed a focused block first.

5.6.1.4 Procedure

See General Methods section

5.6.3 Results

Figure 5.8 shows the likelihood for the correct identification of letter targets when presented with letter distractors collapsed across distractors conditions.

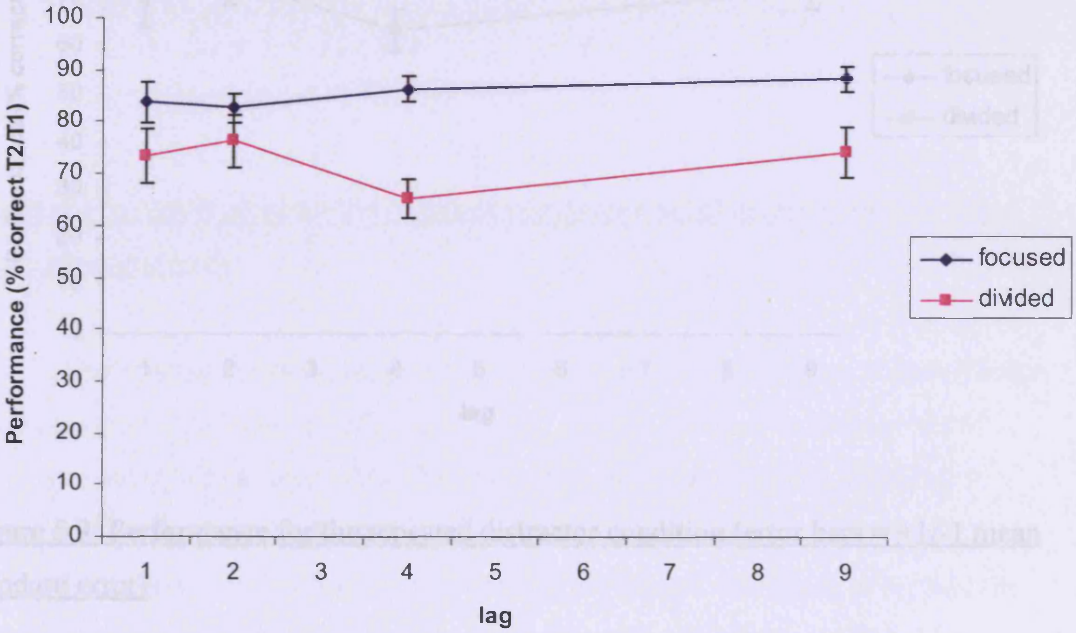

Figure 5.8 Overall performance collapsed across distractor type (error bars = +1/-1 mean standard error)

T1 performance: T1 was reported accurately on 92% of divided attention trials. A repeated-measures ANOVA with distractor type (2 levels) and SOA (4 levels) was carried out on T1 performance and revealed no significant differences (all p's > 0.5).

T2 performance: The initial repeated-measures ANOVA incorporating all distractor types revealed significant main effects of attention $F(1,16) = 4.547$, $mse = .130$, $p < .05$ and distractor type $F(1,16) = 7.267$, $mse = .002$, $p < .02$ as well as for SOA $F(1,16) = 3.552$, $mse = .107$, $p < .03$. These effects were modulated by significant interactions between attention and distractor type $F(1,16) = 11.812$, $mse = .215$, $p < .005$ and between attention and distractor type and SOA $F(2.738,43.806) = 5.159$, $mse = .002$, $p < .01$. However, the interaction between all three factors proved to be non-significant ($p > .05$). A more detailed analysis was carried out to understand the factors that influence the two-way interactions. Given the lack of a significant interaction between all three factors, no further analysis was justified.

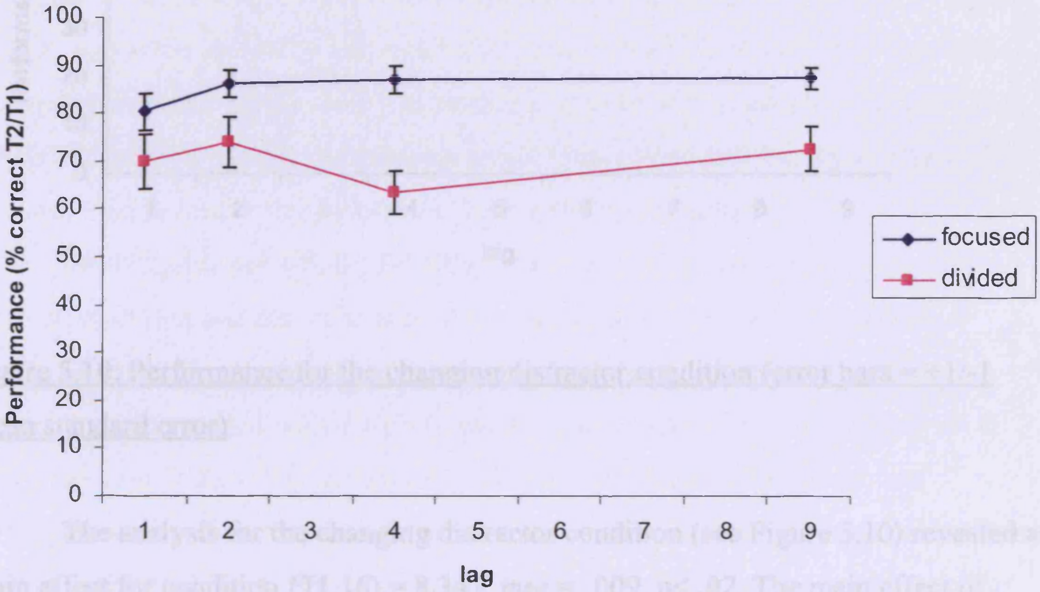

Figure 5.9: Performance for the repeated distractor condition (error bars = +1/-1 mean standard error)

Fig. 5.9 shows the likelihood of correct T2 identification in the repeated distractor condition. An ANOVA revealed only a significant main effect of attention $F(1,16) = 10.335$, $mse = .182$, $p = .005$ whilst SOA proved non-significant ($p > .05$), reflecting the fact that accuracy increased when only one task was required. The interaction between attention and SOA was significant $F(2.804,44.589) = 4.2$, $mse = .001$, $p < .02$. A planned comparison (t-test) to investigate lag 2 sparing comprised a direct contrast between the size of the performance decrement in the divided relative to the focused condition at lags 2 and 4 revealing a significant result (M = 3.677, SD = 6.23), $t(16) = -2.433$, $p < .05$ providing evidence for lag 2 sparing.

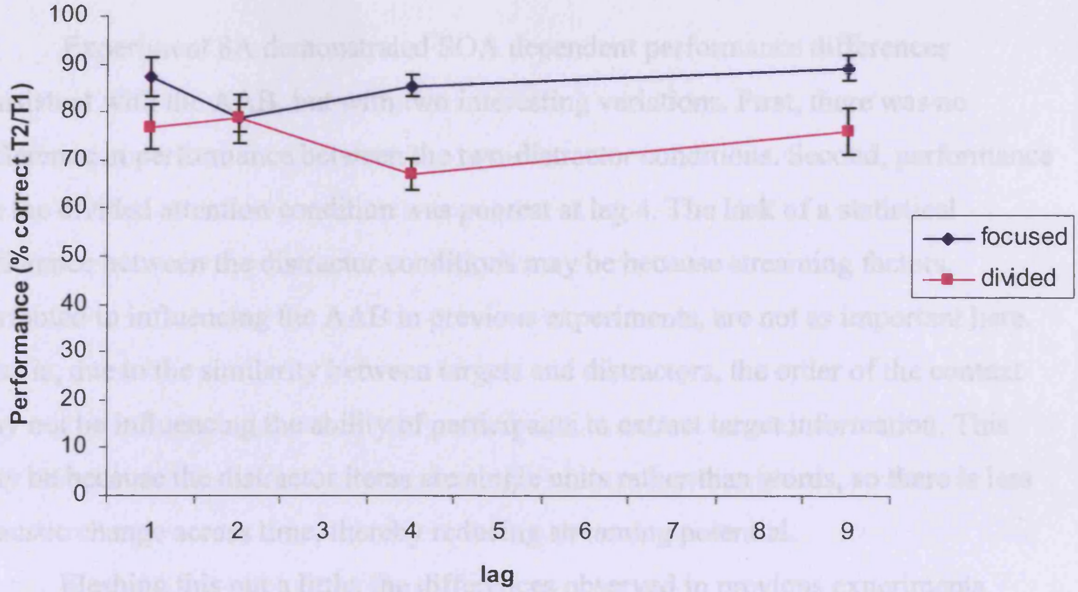

Figure 5.10: Performance for the changing distractor condition (error bars = +1/-1 mean standard error)

The analysis for the changing distractor condition (see Figure 5.10) revealed a main effect for condition $F(1,16) = 8.347$, $mse = .009$, $p < .02$. The main effect of SOA was not significant ($p > .05$). The interaction between condition and SOA however was significant $F(2.898,46.363) = 7.268$, $mse = .116$, $p < .001$. The interaction reflects the fact that the size of the performance decrement at lag 4 in the divided attention condition was markedly larger than at all other lags. The planned comparison to assess lag 2 sparing revealed that the performance decrement at lag 4 was larger than the decrement at lag 2 (M = -11.765, SD = 15.397) $t(16) = 3.151$, $p < .01$.

To summarise, the two-way interaction arising from the initial analysis reflects the deviation in performance at lag 4 for both distractor conditions. Interestingly the performance decrement occurs later when using monosyllabic items and the effect would appear uniform across the context created by the distractors.

5.6.3 Discussion

Experiment 8A demonstrated SOA dependent performance differences consistent with the AAB, but with two interesting variations. First, there was no difference in performance between the two-distractor conditions. Second, performance for the divided attention condition was poorest at lag 4. The lack of a statistical difference between the distractor conditions may be because streaming factors, attributed to influencing the AAB in previous experiments, are not as important here. That is, due to the similarity between targets and distractors, the order of the context may not be influencing the ability of participants to extract target information. This may be because the distractor items are single units rather than words, so there is less acoustic change across time, thereby reducing streaming potential.

Fleshing this out a little, the differences observed in previous experiments between changing and repeated distractor sequences are for low frequency c.v.c words. The relative novelty of these items may require an increased level of processing as compared with a high frequency closed set i.e. letters. If letters are easily recognised then their acoustical attributes may not be so powerful: the participants may effectively be hearing a sequence of letters rather than a collection of sounds. According to this speculation, the context would therefore impose a similar perceptual workload irrespective of the order in which it is presented. That is, for closed stimulus sets it may be that it is not primarily the properties of the context that influence the AAB, but merely the presence of the context.

5.7 Experiment 8B

This experiment was designed in order to characterise the AAB for digits, and provides an opportunity to determine whether similar results to Experiment 8A (blink at lag 4, no differences according to repeated/changing manipulation) can be obtained using another closed set, in this instance digits.

5.7.1 Method

5.7.1.1 Participants

23 (11 female) volunteers, age range from 18 to 27 (mean age = 19.2) were recruited from Cardiff University; their participation was in exchange for course credit. Three participants were excluded as they met or exceeded the 'ceiling' exclusion criteria and were removed from the analysis

5.7.1.2 Materials

All auditory samples were 100 ms in length. Targets were either '1', '4', '7' or '10' plus 50 ms concurrent tone and the order of target presentation was not fixed. Distractor sequences comprised two separable groups; repeated (repetition of '2') and changing (cycling '2', '3' and '6').

5.7.1.3 Design

As Experiment 8A.

5.7.1.4 Procedure

See General Methods section.

5.7.2 Results

Figure 5.11 shows the likelihood for the correct identification of T2 for both attention conditions collapsed across distractor type.

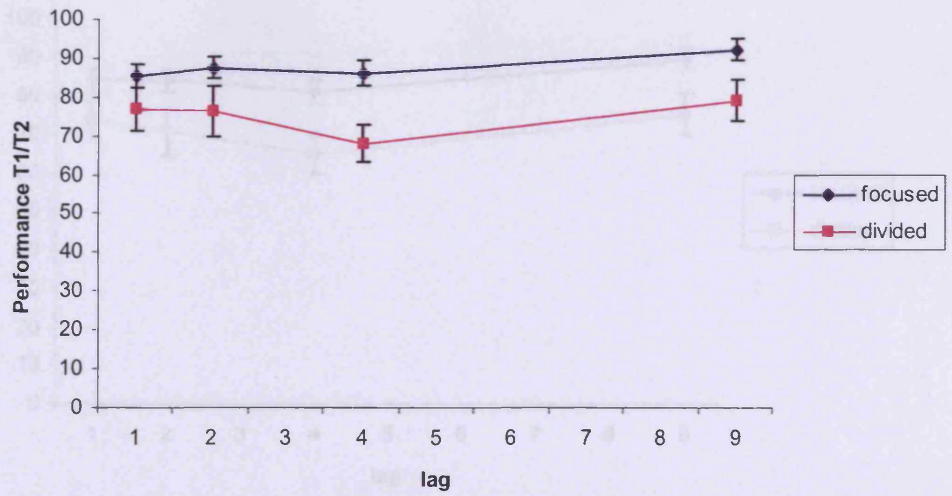

Figure 5.11 Overall performance collapsed across distractor type (error bars = +1/-1 mean standard error)

T1 performance: T1 was reported accurately on 90% of divided attention trials. A repeated measures ANOVA with distractor type (2 levels) and SOA (4 levels) was carried out on T1 performance and as with Experiment 8A revealed no significant differences.

T2 performance: The initial repeated-measures ANOVA incorporating all distractor types revealed significant main effects of attention $F(1,19) = 5.745$, $mse = .364$, $p < .05$, distractor type $F(1,19) = 9.015$, $mse = .233$, $p < .01$ and SOA $F(1,19) = 7.334$, $mse = .003$, $p < .005$. These effects were modulated by a significant interaction between attention and SOA $F(2.589,49.059) = 3.389$, $mse = .007$, $p < .05$. The interaction between all three factors proved to be non-significant ($p > .05$). In the absence of a reliable three-way interaction, the production of a two-way interaction between attention and SOA requires further analysis.

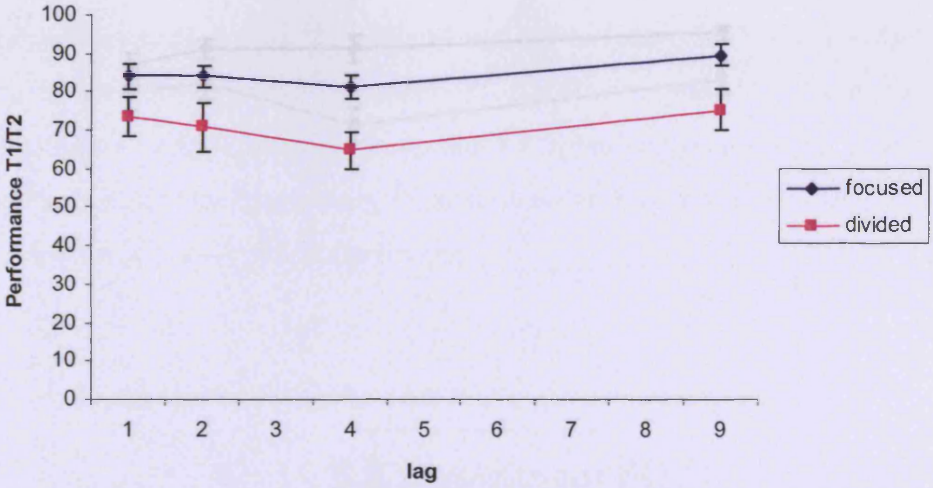

Figure 5.12: Performance for the repeated distractor condition (error bars = +1/-1 mean standard error)

Figure 5.12 shows the likelihood of correct T2 identification in the repeated distractor condition. An ANOVA revealed significant main effects for attention $F(1,19) = 5.034$, $mse = .301$, $p < .05$ and SOA $F(1,19) = 5.355$, $mse = .002$, $p < .01$. The interaction between attention and SOA was not significant ($p > .05$), therefore further investigation is not justified.

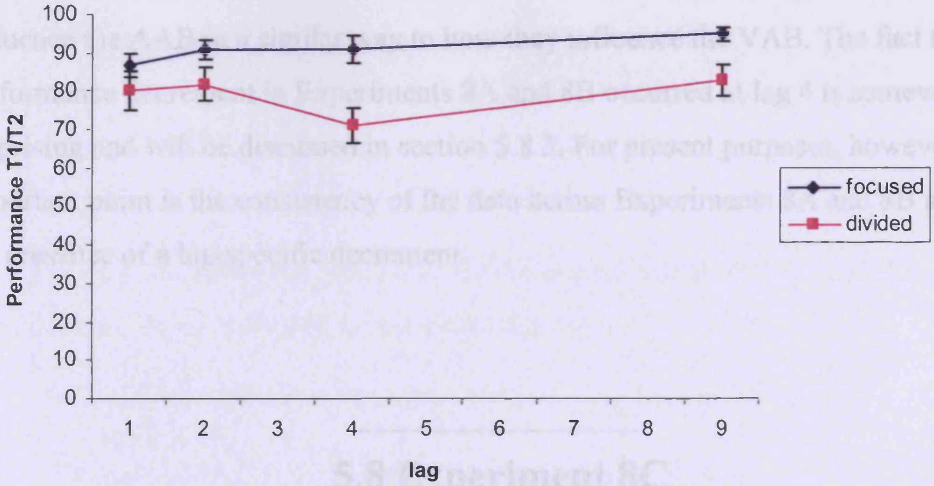

Figure 5.13: Performance for the changing distractor condition (error bars = +1/-1 mean standard error)

The analysis for the changing distractor condition (see Figure 5.13) revealed significant main effects for condition $F(1,19) = 5.336$, $mse = .124$, $p < .05$ and SOA $F(1,19) = 3.393$, $mse = .002$, $p < .05$ as well as a significant interaction between the two factors $F(2.344,44.543) = 2.963$, $mse = .002$, $p < .05$. The interaction reflects the fact that the size of the performance decrement at lag 4 in the divided attention condition is markedly larger than at all other lags. The planned comparison to assess lag 2 sparing revealed that the performance decrement at lag 4 was larger than the decrement at lag 2 (M = 10.33, SD = 11.426) $t(19) = 4.043$, $p = .001$.

To summarise, the two-way interaction arising from the initial analysis reflects the deviation in performance at lag 4 for both distractor conditions. Interestingly the performance decrement occurs later when using monosyllabic items and the effect would appear uniform across the context created by the distractors.

5.7.3 Discussion

Again, as with the previous experiment a specific performance decrement was shown at lag 4, but only for the changing distractor condition. The consistency in the findings across the preceding two experiments is important for the design of Experiment 8C, where digits and letters alternate as targets and as distractors.

Experiment 8C provides an assessment of the extent to which categorical factors influence the AAB in a similar way to how they influence the VAB. The fact that the performance decrement in Experiments 8A and 8B occurred at lag 4 is somewhat surprising and will be discussed in section 5.8.3. For present purposes, however, the important point is the consistency of the data across Experiments 8A and 8B alongside the presence of a lag-specific decrement.

5.8 Experiment 8C

The previous two experiments utilised targets and distractors were from the same stimulus set - digits or letters. The present experiment presented digit targets embedded within both repeated and changing alphabetical distractor sequences. This combination was chosen to mirror the work of Arnell and Jenkins (2004), albeit using a unimodal approach. Arnell and Jenkins demonstrated a reduction in the magnitude of the cross modal AB with a change in stimulus category between target and distractor. At issue here is whether this holds true within the auditory domain.

5.8.1 Method

5.8.1.1 Participants

21 (13 female) volunteers, age range from 18 to 25 (mean age = 19.1) were recruited from Cardiff University; their participation was in exchange for course credit. Four participants' data was excluded from the analysis because their performance exceeded the ceiling criterion (see General Methods for explanation).

5.8.1.2 Materials

All auditory samples were 100 ms in length. Targets were either '1', '4', '7' or '10' with target presentation order not fixed. Distractor sequences comprised two separable groups; repeated (repetition of 'B') and changing (cycling 'B', 'C' and 'D').

5.8.1.3 Design

As Experiment 8A.

5.8.1.4 Procedure

See General Methods section.

5.8.2 Results

Figure 5.14 shows the likelihood for the correct identification of T2 for both attention conditions collapsed across distractor type.

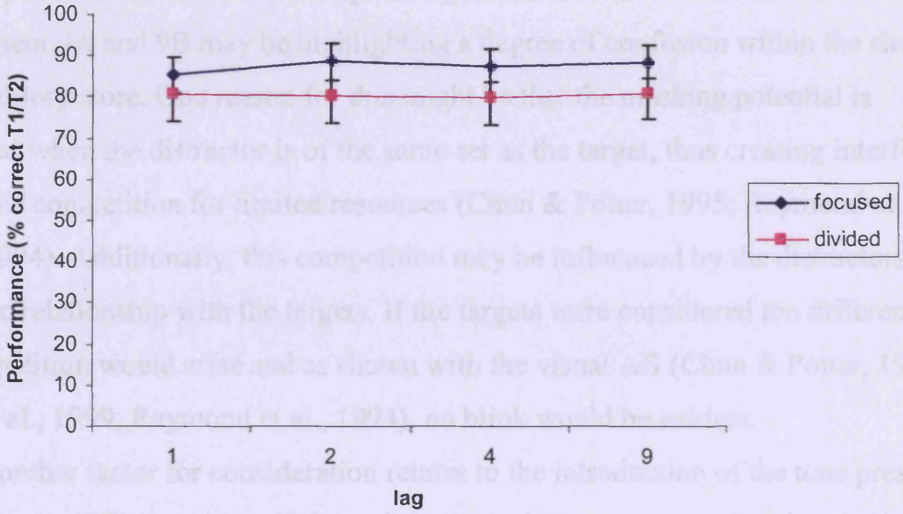

Figure 5.14: Overall performance with digit targets in letter distractors collapsed across condition (error bars = +1/-1 mean standard error)

T1 performance: T1 was reported accurately on 90% of divided attention trials. A repeated measures ANOVA with distractor type (2 levels) and SOA (4 levels) was carried out on T1 performance and revealed no significant differences.

T2 performance: The initial repeated-measures ANOVA incorporating all distractor types revealed only a significant main effect of attention $F(1,17) = 6.395$, $mse = .115$, $p < .05$. Due to the lack of a significant difference between attention conditions, no further analysis can be carried out. To summarise, identifying two digit targets when presented within letter distractor is harder than identifying just one. However, this difference is resilient to changes in context (distractor types) and to SOA effects.

5.8.3 Discussion

Experiment 8C showed that targets from a different category to the distractors are not effectively masked reducing the workload of the sensory processing and are therefore easy to extract from the sequence. This may relate to the notion that streaming, or the creation of streams, relies on the items sharing similar acoustical properties. However, with the short, single item distractors there is less chance of separate perceptual streams being formed as the items are defined by timbre rather than by pitch. Therefore, the SOA-specific performance decrement shown in both Experiment 9A and 9B may be highlighting a degree of confusion within the short-term auditory store. One reason for this might be that the masking potential is increased when the distractor is of the same set as the target, thus creating interference due to the competition for limited resources (Chun & Potter, 1995; Raymond et al. 1992; 1994). Additionally, this competition may be influenced by the distractors' semantic relationship with the targets. If the targets were considered too different then no competition would arise and as shown with the visual AB (Chun & Potter, 1995; Maki et al., 1999; Raymond et al., 1994), no blink would be evident.

Another factor for consideration relates to the introduction of the tone presented concurrently with the targets. This methodological change was undertaken in light of the work of Karen Arnell, specifically from Arnell and Larson, 2002 (a partial replication of Arnell and Larson, 2001 will be reported in the next chapter). The interesting factor from the data of the previous three experiments is that of the lag 4 decrement. It is worth noting that a methodology incorporating both a concurrent tone and a similar SPR (10.72 items/s) demonstrated a later performance decrement (Arnell & Jolicoeur, 1999).

5.9. General Discussion

The overall picture of the third empirical series can be summarised as follows. The AAB effect can be abolished by reducing the three-distractor item bond by increasing exposure to both distractors before the target is presented, and by increasing the participants' knowledge of the target items. However, the AAB cannot simply be attributed to a stimulus driven artefact, as during the 'blinked' period a categorical level of processing is engaged: the AAB is attenuated if the targets are of a different stimulus set than the distractors. This finding mirrors those in for the VAB (Chun & potter, 1995; Maki et al., 1999).

Chapter 6

Empirical Series 4: Switching of attentional set in the AAB

6.1 Abstract

The present empirical series examined the influence of modality changes and set switches on the AAB. Initially the task demands for T1 and T2 were kept the same whilst the modality (either visual or auditory) in which they were presented was changed (Exps 9A & 9B). Reliable ABs were demonstrated for the within modality conditions when auditory stimuli utilised a North American voice (Exps. 9A: stimuli kindly provided by Karen Arnell) whereas utilising a UK (South Wales) accent produced T1-T2 SOA interactions for both within and cross-modality conditions (Exp. 9B). Additionally, an auditory only experiment (Experiment 10) replicated the auditory within condition of Experiment 9B. The implementation of a switch of task demands between T1 and T2 (Experiment 11) within the auditory modality did not remove the AAB; however, the context in which the targets were presented created differences in performance. A changing distractor context removed the AAB, contrary to previous findings. The no distractor condition produced a typical AAB performance curve whilst the repeated distractor elicited lag 1 and 2 sparing. These counterintuitive findings are explained in terms of strategy: the incorporation of a predictable switch allows greater preparation, resulting in higher performance at early SOAs.

6.2 Introduction

The current series of experiments expands upon the preceding work in which perceptual factors were shown to influence the likelihood of an AAB being observed. The aim of this series was to examine the AAB in experiments where there were changes in task and/or in attentional set across T1 and T2. Switches in task-set were examined in cross-modal and unimodal experiments. Amodal attentional-set switches focus on categorical changes between target and distractors to examine levels of processing afforded targets. For the VAB, 'blinked' target items are afforded categorical processing (Luck, Vogel & Shapiro, 1996; Vogel, Luck & Shapiro, 1998). That is, the VAB is abolished when the targets and distractors are from dissimilar categories (Raymond et al, 1995; Maki et al., 1999 c.f. Chapter 5).

By examining the within and cross modality ABs it is therefore possible to determine similarities and correspondences between the operations carried out in the visual and auditory attentional systems. If switching influences the AAB in a similar way to the VAB then the data would suggest that the AAB and VAB have a common processing locus, at least to some degree (Arnell & Jolicoeur, 1995, 1999; Arnell & Larson, 2002).

6.3 Experiment 9A

This initial experiment is a replication of the study by Arnell and Larson (2002, Experiment 2) in which the potential influence of preparatory task switching was addressed. Preparatory task switching relates to target set expectations for T1 and T2. If the task order between T1 and T2 is fixed, for example if the task for T1 was identification of a digit between 1 - 4 and the task for T2 was detecting the presence or absence of an 'X', (Arnell & Jolicoeur, 1999; Raymond et al. 1992), then the participant is in theory able to prepare for the change in task in an attempt to reduce errors. What this means, however, is that changes in T2 performance across lag may be due to switch costs associated with the differences between tasks for T1 and T2 (Potter et al., 1998). Arnell and Larson (2002) designed a cross-modal AB paradigm in which neither task nor modality of T1 presentation could be predicted from the presentation of T2. The task was to identify two targets, and these could be presented with equal likelihood in either modality. Arnell and Larson argued that removing a predictable order from the paradigm allows greater measurement of the specific attentional demands imposed upon the participant, and a way to study the cross modal AB independently of switch costs.

The experiments in the previous empirical series required participants to identify two target words (either one of 'cod'/'cot' or 'nab'/'nap') within a stream of non-word distractors. T1 could be any of the four targets, but targets could only be one of a pair, e.g. if T1 was 'cod' the participant knew that T2 could only be either of the 'nab'/'nap' pair. This may have lead participants to change task set after T1. Although this reconfiguration of task-set offers benefits by virtue of attending to only two possible stimuli rather than four, there are also potential costs, these being decreased performance accuracy at short SOAs. Task set reconfiguration costs have been shown even with predictable switches (Monsell, Sumner & Walters, 2003).

Following Arnell & Larson (2002 Exp. 2), in RSVP and RAP tasks, letter targets were presented within a stream of letter distractors. Targets (K, L, R and Y) had an equal likelihood of presentation, with T1 and T2 having an equal probability of being presented in either modality. Task demands were the same for each target; participants were required to identify both target letters within the stream. This design does not promote a preparatory shift in task set because T1 does not predict T2.

6.3.1. Method

6.3.1.1 Participants

26 (16 female) volunteers, age range from 18 to 25 (mean age = 19.8) were recruited from Cardiff University; all received a small honorarium for their participation

6.3.1.2 Materials

Auditory stimuli were 80 ms in length whilst visual stimuli were presented for 80 ms. The monitor refresh rate was set at 80 Hz. Visual stimuli were made up of all the letters of the alphabet apart from W. The visual letters were uppercase 36-point New Times Roman font. Visual stimuli were presented one at a time in a RSVP stream in the centre of the screen upon a white background. Distractor items were in black whilst target letters (K, L, R and Y) were dark blue. Auditory stimuli were spoken letters in compressed speech. All letters of the alphabet were included excluding the letter 'W'. The stimuli were those used by Arnell and Larson (2002). Target letters were never used as distractors. Auditory items were presented in the right ear of the headphones with a tone presented concurrently in the left ear with the target letter/s. The tone (sine wave) was 530 Hz in pitch and 50ms in duration. For details of sound generation, see General Methods. Karen Arnell kindly provided the sound files.

6.3.1.3 Design

The three repeated measures were T1 modality (auditory or visual), T2 modality (auditory or visual) and SOA (83, 250, 416, and 750 ms), all within participants and fully randomised. The number of letters presented before T1 (4, 6, 8, 10 or 12) was determined pseudo-randomly: each occurred equally often in each set of 40 trials. Eight letters always followed T2 irrespective of T1-T2 SOA. The experiment consisted of 400 trials with an imposed break halfway through, which was a minimum of 30 seconds in length.

6.3.1.4 Procedure

See General Methods section.

6.3.2 Results

The likelihood of the correct identification of both T1 and T2 collapsed across modality is presented in Figure 6.1: the scale of the graphs for the current experiment has been truncated to facilitate visual inspection of the data. Arnell and Larson, (2002) presented their data somewhat differently (performance calculated for T1 and T2 separately and irrespective of actual order of target presentation) and for ease of comparison the same method of presentation as that adopted by Arnell and Larson is shown in appendix 2. The experimental design does not incorporate two attention conditions (as with previous experiments in this empirical series) as each trial required the identification of T1 and T2. The figures and resulting analyses given below describe the likelihood of correct T2 identification contingent upon correct identification of T1, as with the previous empirical work in this thesis. All trials in which T1 was the same as T2 were removed before the analysis in order to reduce the possible impact of repetition blindness (Kanwisher, 1990).

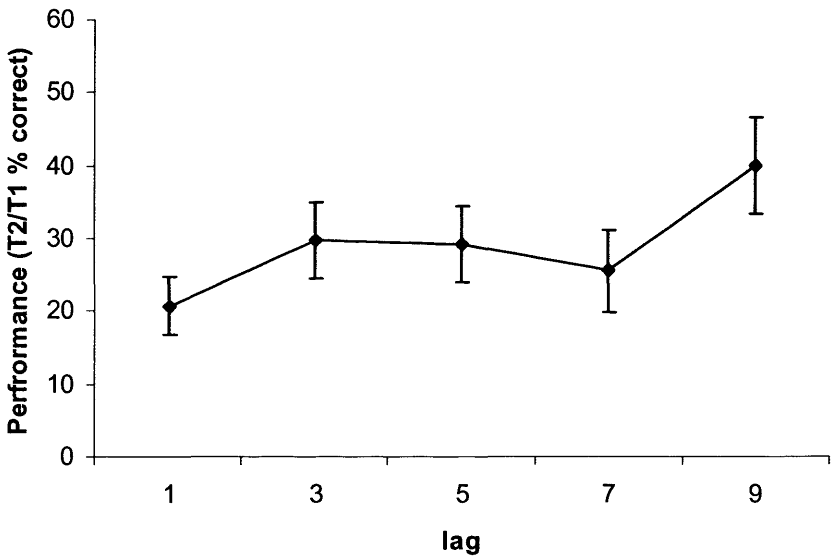

Figure 6.1: Performance collapsed across modality demonstrating performance for T2 given correct identification of T1 (error bars = +1/-1 mean standard error).

T1 performance: On average T1 was reported as correct on 64.1% of all trials. An ANOVA, with two repeated measures, condition (vis-vis, vis-aud, aud-vis & aud-aud) and SOA (corresponding to lags 1 (80 ms), 3 (240 ms), 5 (400 ms), 7 (580 ms) & 9 (720 ms) revealed only a significant main effect for condition $F(3,75) = 4.677$, *mse* = 72.405, $p<.001$. The main effect for SOA and the interaction did not reach significance ($p> .05$). The significant difference in performance across condition may be due to the dissimilarity between performance for the auditory within (M = 54.583, SE = 1.865) and the visual within condition (M = 71.500, SE = 4.240)

T2 performance: The initial repeated measure ANOVA incorporating condition (vis-vis, vis-aud, aud-vis & aud-aud) and SOA (corresponding to lags 1, 3, 5, 7 & 9) revealed significant main effects for condition $F(3,75) = 15.637$, *mse* = 25.463, $p<.001$ and SOA $F(4,100) =54.449$, *mse* = 11.551, $p<.005$. These effects were moderated by a significant interaction between both factors $F(4,100) = 2.419$, *mse* = 49.777, $p<.05$. To understand further the influence of condition upon SOA separate analyses were carried out for each condition.

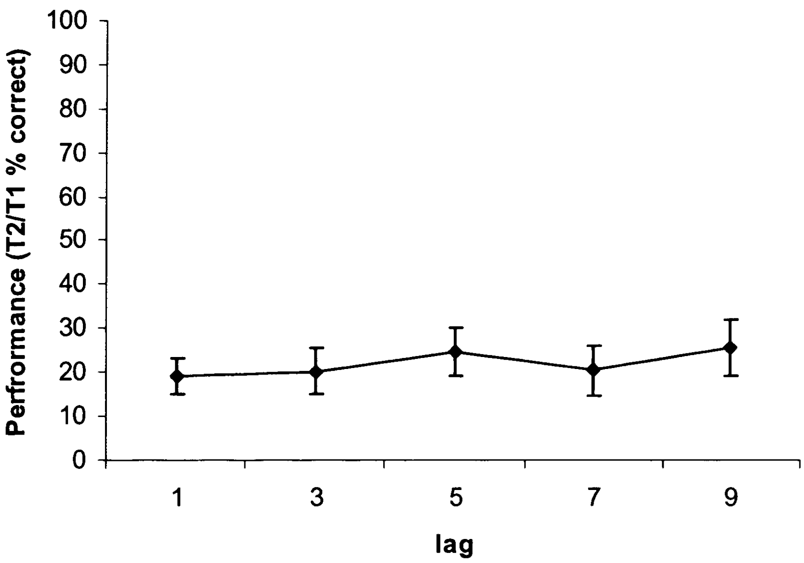

Figure 6.2: Auditory within condition demonstrating performance for an auditory T2 given correct identification of an auditory T1 (error bars = +1/-1 mean standard error).

Figure 6.2 shows the likelihood of correct identification of an auditory T2, as a function of the correct identification of an auditory T1. An ANOVA revealed significant main effects of SOA $F(4,100) = 3.813$, $mse = 31.427$, $p<.05$. Figure 6.2 shows that performance is more likely to improve as the number of intervening distractor items between the two targets increases. The general increase in performance across SOA was analysed with a series of planned comparisons between lag 1 and lag 3; $t(25) = -.696$, (M = -1.615, SD = 11.839), $p> .05$, lag 1 and lag 5 ; $t(25) = -2.478$, (M = -9.077, SD = 18.678), $p< .05$ and lag 1 and lag 9 ; $t(25) = -3.859$, (M = -12.461, SD = 16.919), $p< .01$.

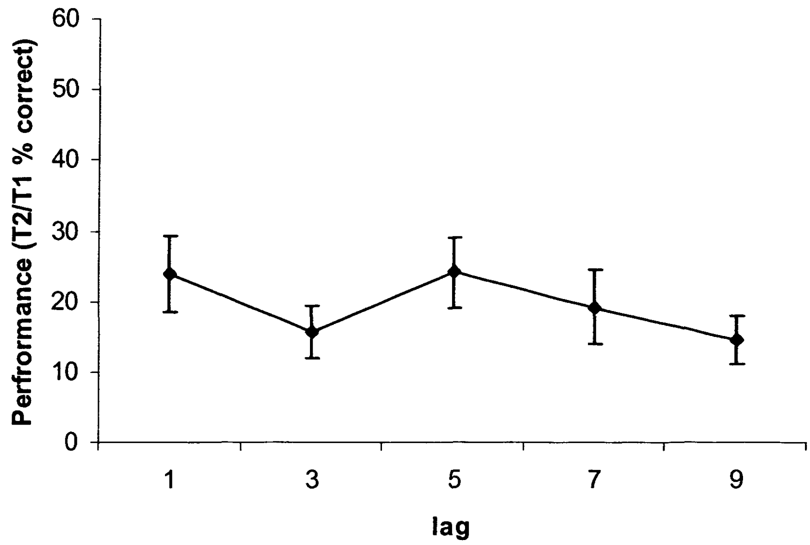

Figure 6.3: Auditory crossed condition showing performance for an visual T2 given correct identification of a auditory T1 (error bars = +1/-1 mean standard error).

The analysis of the cross-modality auditory (auditory T1 and visual T2) condition (see Fig. 6.3) revealed no effect of SOA. A planned comparison between performance at lag 1 and lag 3 revealed no evidence for lag 1 sparing $t(25) = 1.738$ (M = 8.231, SD = 14.142), $p>.05$, although the graph shows that there is some decrement in performance.

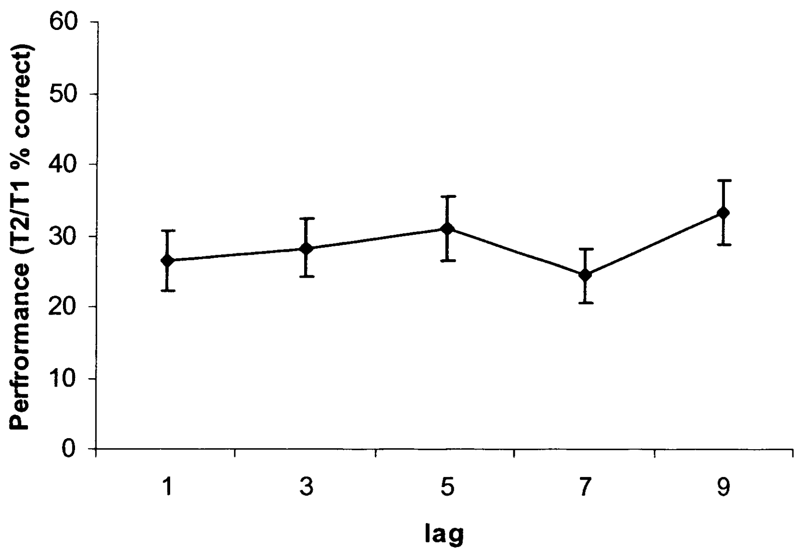

Figure 6.4: Visual-crossed condition showing performance for an auditory T2 given correct identification of a visual T1 (error bars = +1/-1 mean standard error).

The same analyses were carried out on the cross-modality visual (visual T1 and auditory T2) condition (Fig 6.4) and no reliable effects were obtained.

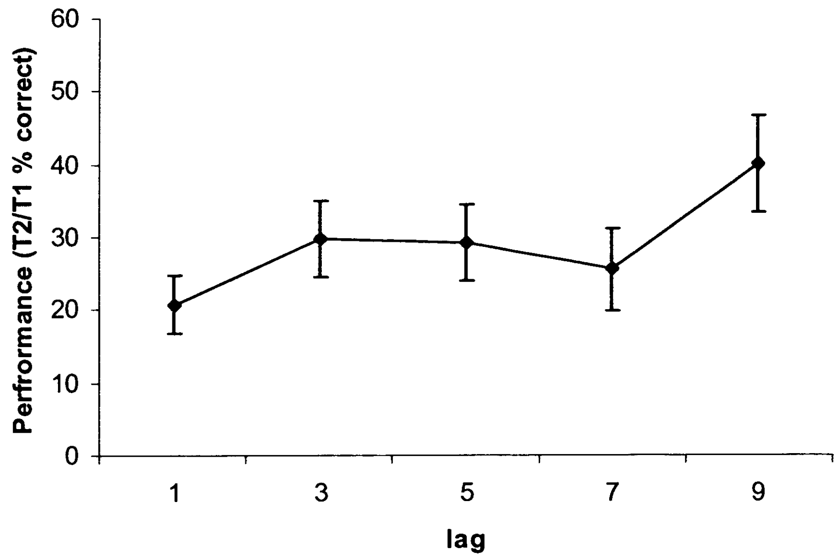

Figure 6.5: Visual within condition demonstrating performance for a visual T2 given correct identification of a visual T1 (error bars = +1/-1 mean standard error)

An ANOVA on the likelihood of correct identification for both T1 and T2 for the within visual modality (visual T1 and visual T2) condition revealed a significant main effect of SOA $F(4,100) = 4.158$, $mse = 9.298$, $p=.01$. Fig. 6.5 shows a qualitatively similar recovery in performance as in Fig 6.2, whereby the likelihood of correct identification of T2 rises as the numbers of item intervening between the two targets increases. As with the auditory within condition a series of planned comparison s analysed the increase in performance between lag 1 and lag 3; $t(25) = 1.881$, (M = -9.000, SD = 24.39180), $p> .05$, lag 1 and lag 5 ; $t(25) = -2.208$, (M = -8.461, SD = 19.541), $p< .05$ and lag 1 and lag 9 ; $t(25) = -4.057$, (M = -19.1538, SD = 24.074), $p< .001$.

In summary, the two-way interaction involving the target modality condition that came about in the initial global analysis reflects the changes in performance with SOA when both targets were presented within the same modality.

6.3.3 Discussion

Changes in performance according to SOA were obtained only when T1 and T2 were presented in the same modality. Comments on the interpretation of these results are deferred until after experiment 9B, which is structurally identical to 9A but involves the use of a different set of auditory stimuli, for the reasons described below.

6.4 Experiment 9B

The present experiment expands upon the previous experiment by addressing the nature of the auditory component, a potentially problematic factor in Experiment 9A. The previous experiment utilised the same auditory stimuli used by Arnell and Larson, Due to the nationality of speaker (North American), however, some participants reported finding the stimuli difficult to comprehend.[6] The present experiment utilised a voice was that of a native English speaker from a local area (South Wales). If stimuli are more discriminable then according to one perspective, targets may be segregated from the distractor items stream more effectively, thus theoretically providing more opportunity for their interaction (Chun & Potter, 1995). This interaction would in turn produce a larger AB. The same design and procedure as Experiment 9A was employed with the exception of the use of the different auditory stimulus set.

6.4.1 Method

6.4.1.1 Participants

17 (13 female) native English speaking volunteers, age range from 18 to 24 (mean age = 20.3) were recruited from Cardiff University; all received course credit in return for their participation.

6.4.1.2 Materials

Stimuli (targets and distractors) were the same as Experiment 9A, although auditory stimuli were acquired and processed using the method outlined in the General Methods chapter.

[6] This concern arose initially from comments by the participants in experiment 9A. On hearing the practice trials, remarks were made about the lack of clarity of the auditory presentation. The fact that less than 55% of T1 stimuli were identified correctly was also considered problematic.

6.4.1.3 Design

As Experiment 9A.

6.4.1.4 Procedure

As Experiment 9A.

6.4.2 Results

The likelihood of the correct identification of T2 given the correct identification of T1 collapsed across target modality condition can be seen in Figure 6.7. In keeping with the procedure for Experiment 9A, trials in which T1 and T2 were the same item were removed prior to analysis.

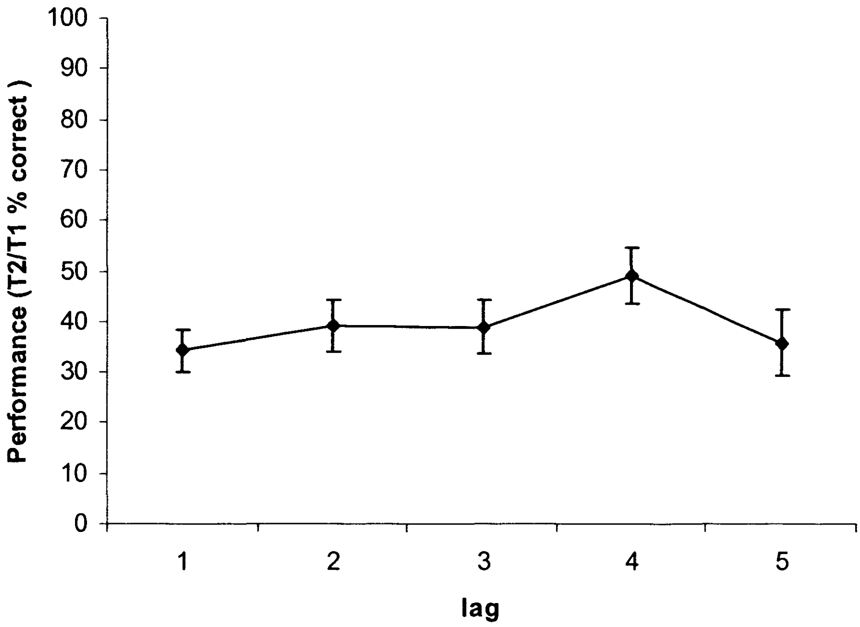

Figure 6.6: Performance for T2 after a correctly identified T1 collapsed across target modality (error bars = +1/-1 mean standard error).

T1 performance: On average T1 was reported as correct on 79.7% of all trials. An ANOVA, with two repeated measures, condition (vis-vis, vis-aud, aud-vis & aud-aud) and SOA (corresponding to lags 1 (80 ms), 3 (240 ms), 5 (400 ms), 7 (580 ms) & 9 (720 ms) revealed only a significant main effect for condition $F(3,48) = 21.075$, *mse* $= 50.471$, $p<.001$. This arose from performance for the visual crossed condition (M =

93.941 SD = 1.868) which was greater than all the other conditions; the auditory within (M = 78.647 SD = 3.411), the visual within (M = 70.000 SD = 3.392) and the auditory crossed (M = 76.294 SD = 3.792) conditions

T2 performance: The initial repeated measures ANOVA incorporating condition (vis-vis, vis-aud, aud-vis & aud-aud) and SOA (lags 1, 3, 5, 7 & 9) revealed significant main effects for condition $F(3,48) = 10.890$, $mse = 136.780$, $p<.001$ and SOA $F(4,64) = 10.124$, $mse = 56.347$, $p<.001$. These effects were moderated by a significant interaction between both factors $F(4,64) = 4.491$, $mse = 55.249$, $p<.005$. Subsidiary analyses were carried out for each condition separately.

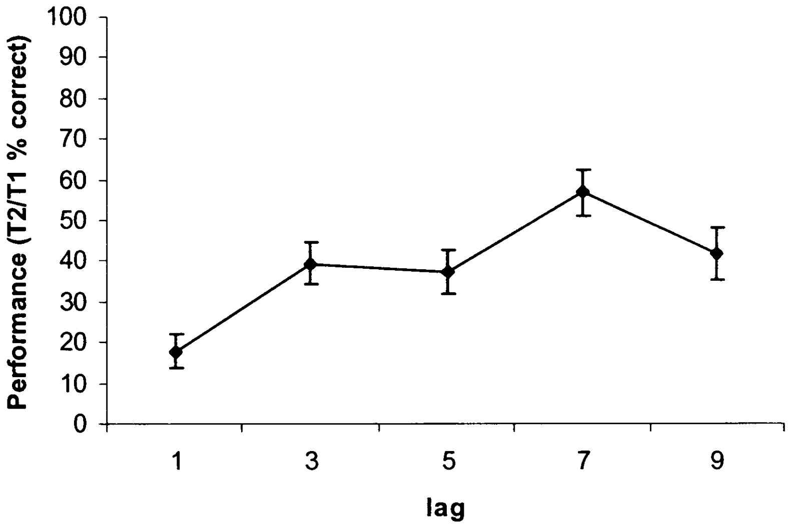

Figure 6.7 Auditory within condition demonstrating performance for an auditory T2 given correct identification of an auditory T1 (error bars = +1/-1 mean standard error).

Figure 6.7 shows the conditional likelihood of correct identification of T2 when both targets were presented in the auditory modality. An ANOVA revealed a significant main effect of SOA $F(1,64) = 6.743$, $mse = 27.454$, $p<.001$. Figure 6.7 shows that performance rises as a function of increasing SOA, and this impression was confirmed by statistical analyses, which showed that performance was superior at longer SOAs. A series of planned comparisons were carried out between performance at lag 1 and lag 3; t(16) = -2.629, (M = -21.529, SD = 33.761), $p< .025$, lag 1 and lag 5 ; $t(16) = --3.195$, (M = -19.412, SD = 25.047), $p< .005$ and lag 1 and lag 9 ; $t(16) = -2.219$, (M = -23.882, SD = 44.376), $p< .05$..

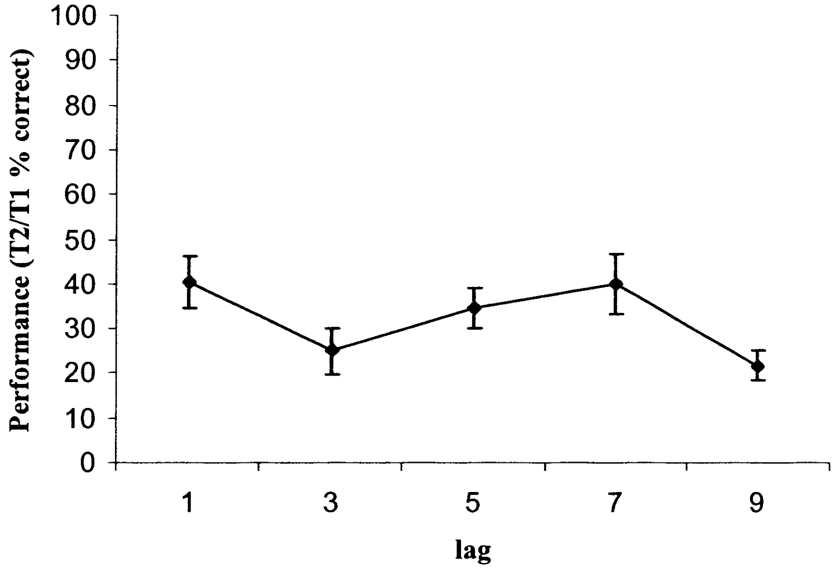

Figure 6.8: Auditory crossed condition demonstrating performance for an visual T2 given correct identification of a auditory T1 (error bars = +1/-1 mean standard error).

The analysis of the cross-modality auditory (auditory T1 and visual T2) condition (see Fig. 6.8) revealed a significant main effect of SOA $F(4,64) = 7.370$, $mse = 43.890$, $p<.005$. A planned comparison was carried out between the performance for T2 at lag 1 and lag 3 $t(16) = 4.261$ (M = 15.412, SD = 14.912), $p<.005$, demonstrating lag 1 sparing with a modality switch in attentional set. However, a planned comparison between performance at lag 2 and lag 9 did not show a reliable difference $t(16) = .747$ (M = 3.294, SD = 18.193), $p>.05$.

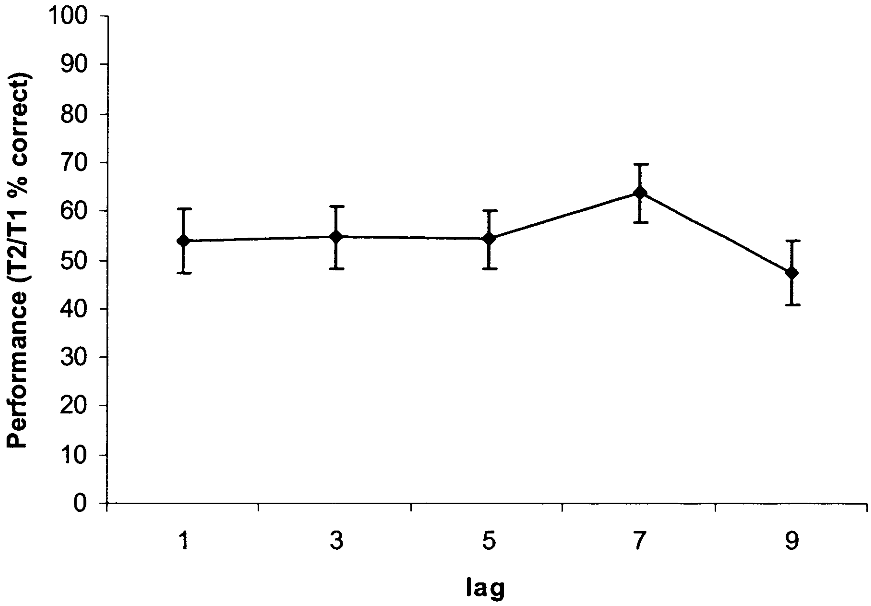

Figure 6.9: Visual crossed condition, showing performance for a auditory T2 given correct identification of an visual T1 (error bars = +1/-1 mean standard error).

The same analysis was carried out on the cross-modality visual (visual T1 and auditory T2) condition (Fig 6.9), revealing a significant main effect for SOA $F(4,64) = 4.589$, $mse = 44.934$, $p < .005$. The difference according SOA was due to a significant change in performance between lag 5 and lag 7 $F(1,16) = 5.601$, $p < .05$ and between lag 7 and lag 9 $F(1,16) = 12.732$, $p < .005$.

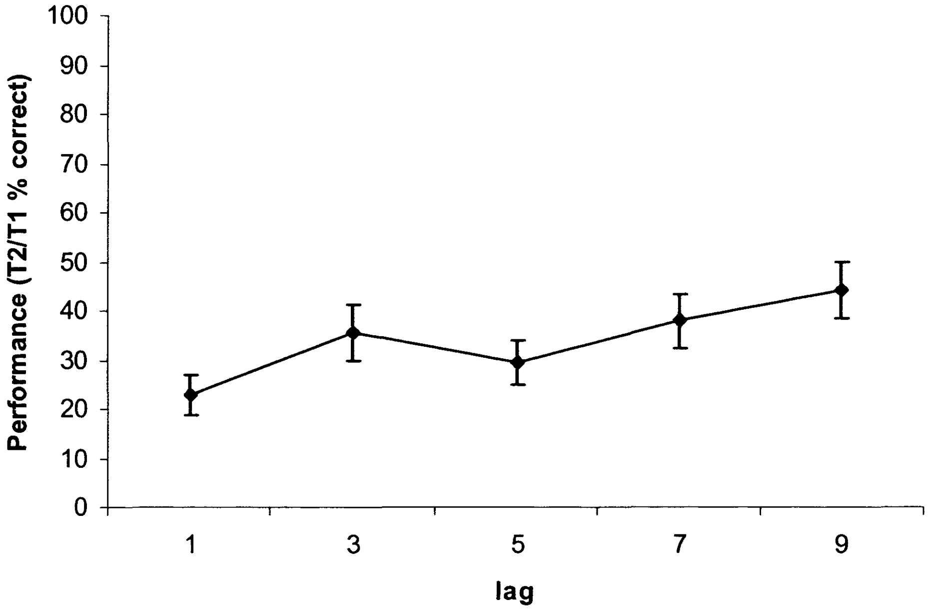

Figure 6.10: Visual within condition (visual T1- visual T2) mean accuracy plotted as a function of target number (error bars = +1/-1 mean standard error)

Figure 6.10 shows the likelihood of correct identification for T2 given the correct identification of T1 for the within visual modality (visual T1 and visual T2) condition. An ANOVA demonstrated a significant main effect of SOA $F(4,64) = 2.700$, $mse = 44.672$, $p < .05$. A series of paired comparisons between lag 1 and lag 3; $t(16) = -1.456$, ($M = -12.823$, $SD = 36.3115$), $p > .05$, lag 1 and lag 5 ; $t(16) = -.847$, ($M = -6.588$, $SD = 32.0762$), $p > .05$ and lag 1 and lag 9 ; $t(16) = -2.661$, ($M = -21.294$, $SD = 32.990$), $p < .025$ showed that performance rises as the number of intervening items between the two targets increases.

6.4.3 Discussion

Qualitatively similar findings were obtained in Experiment 9B as those demonstrated in Experiment 9A. The likelihood of correct identification of T1 was higher in Experiment 9B, as was the resulting conditional probability of identifying T2. These findings indicate that the stimulus set used in the latter experiment improved the overall accuracy of identification.

The data presented here are in a different format to that presented by Arnell and Larson (for a direct comparison see Appendix 2), but is in line with the way in which results have been presented in earlier chapters, and is in line with the way in which AB data are typically presented in the literature. The two experiments provide tentative evidence for a cross modal AB, as highlighted by lag 1 sparing in the Auditory T1 Visual T2 condition in Experiment 9B. A similar pattern is evident in Experiment 9A, but the difference did not reach significance, likely because of the larger proportion of trials that were rejected in Experiment 9A than in Experiment 9B due to reduced T1 performance. The within modality conditions in both experiments showed no evidence of an AB, at least if lag 1 sparing is part of the criterion for an AB, but performance did improve with increasing SOA.

These results must be interpreted cautiously given the fact that no focused attention condition was incorporated in these studies. These data, nonetheless, suggest again that the context within which target items are presented exerts a strong influence on the likelihood of obtaining an AAB. Because of this, and in keeping with the focus on the AAB in this thesis, a further experiment was run employing only the auditory within conditions that were used in Experiments 9A and 9B.

6.5 Experiment 10

Experiments 9A and 9B replicated the findings for the auditory within condition of Arnell and Larson (2001): T2 performance was lowest at the shortest SOA. Arnell and Larson argue that this effect for the auditory within condition is an AB and the pattern of data is a product of a reduction in possible preparatory task switching. This would suggest that the lack of predictability of the task provides an environment that truly exposed the processing deficits that arise when two targets must be processed in rapid succession. If the results provided during the cross modal procedure do truly reduce the cost or benefit of preparing attentional resources then similar results will be elicited in experiments with no changes of modality. The question of whether it is reasonable to claim that an AB can actually be obtained in the absence of lag 1 sparing will be returned to in subsequent discussions.

6.5.1 Method

6.5.1.2 Participants

16 (12 female) native English speaking volunteers aged between 19 and 26 (mean age = 19.2) from Cardiff University participated in a 1 hour session and received course credit in return for their time.

6.5.1.2 Materials

Auditory stimuli were the same as used in Experiment 9A. Auditory stimuli were compressed speech, all letters of the alphabet excluding 'W'. The concurrent target tone was the same as that used in experiment 9B.

6.5.1.3 Design

The two repeated measures were target number (T1 or T2) and SOA (83, 250, 416, and 750 ms), all within subjects and randomised fully. The experiment consisted of 400 trials with an imposed break halfway through of a minimum of 30 seconds duration.

6.5.1.3 Procedure

As Experiment 9B

6.5.2 Results

Again, scores were calculated in the same manner as the previous experiments, as correct irrespective of order. Mean target accuracy was calculated and has been plotted in Figure 6.12.

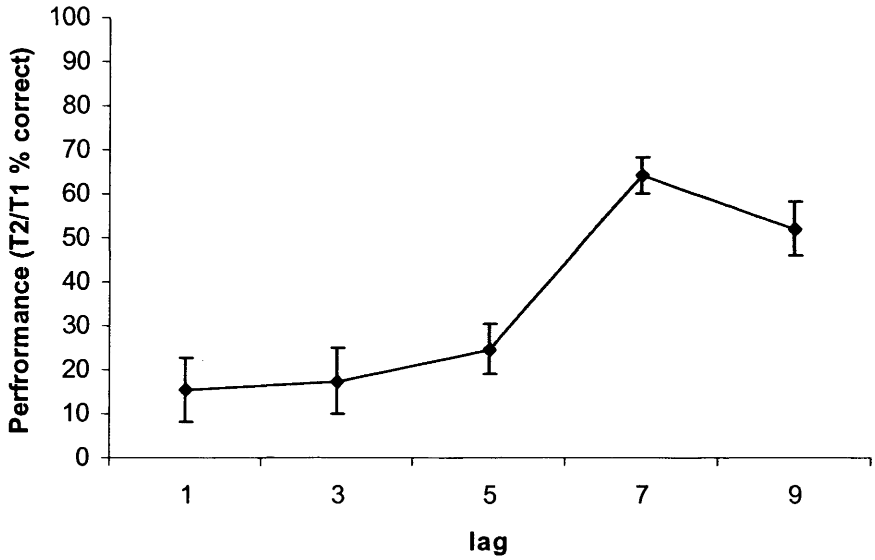

Figure 6.11: Auditory within condition (auditory SOA- auditory SOA) mean correct responses as a function of target number (error bars = +1/-1 mean standard error).

Figure 6.11 shows the likelihood of correct identification of T2 given correct identification of T1 when both targets were presented in the auditory modality. An ANOVA revealed a significant main effect of SOA $F(4,60) = 8.993$, $mse = 72.687$, $p<.001$, and Figure 6.12 shows that performance rises as a function of increasing SOA. A series of planned comparisons between lag 1 and lag 3; t(16) = -.554, (M = -2.083, SD = 14.554), $p> .05$, lag 1 and lag 5 ; $t(16) = -2.900$, (M = -9.350, SD = 12.488), $p< .05$ and lag 1 and lag 9 ; $t(16) = -4.367$, (M = -63.700, SD = 32.550), $p< .001$ confirmed that performance rises as the number of intervening items between the two targets increased..

6.5.3 Discussion

The present study provided a very similar behavioural pattern to Experiments 9A and 9B, which utilised the same or similar auditory stimuli. Performance was at its lowest at the shortest SOA, with performance then rising as the number of distractor items between the two targets increased.

These findings suggest that simply including the cross modal conditions in the experiment is not responsible for the fact that performance for this stimulus set increases with increasing SOA and shows no evidence of lag 1 sparing. The findings suggest that it is the properties of the stimulus set, or the fact that T1 did not predict T2, that is responsible for the differences between the divided attention conditions in Experiments 9A, 9B and 10, and those in earlier experiments in this thesis. It is also the case, however, that the nature of the distractor sequences is different in these experiments from in the previous experiments

The work concerning the visual AB suggests that the phenomenon of lag 1 sparing is vulnerable to a switch between targets (Potter et al., 1998; Visser et al., 1999). However, Lag 1 sparing was eliminated with a randomly ordered context (Experiments 2, 9A, 9B and 10) when both targets are presented in the auditory modality when no switch was in principle required. Therefore, the next experiment was designed in order to investigate the importance of task switches by imposing a categorical shift between T1 and T2 within an ordered context.

6.6 Experiment 11

The present experiment was designed in order to investigate the influence of a change in T1-T2 stimulus set on the AAB. The assumption is that this manipulation will result in a shift in attentional set after the presentation of T1. Experiment 11 examined the possibility that a task switch, which is believed to engage central capacity limitations (Pashler, 1990; Potter et al., 1998), produces a similar pattern of performance decrement in the auditory modality to that seen in the visual modality. In this experiment, targets T1 and T2 belonged to different stimulus categories, either

‘Cod, Cot, Nab or Nap’ or ‘1, 4, 7 or 10’. The target order was fixed, whereby T1 was derived from one stimulus set whilst T2 was from the other. The contexts in which the targets were set were the changing, repeated and no distractor contexts used in many of the previous experiments. The context manipulation allows examination of any cost induced by a category change in relation to the acoustic properties of the distractors. If the visual and auditory modalities behave in a similar way then a task switch should eliminate the AAB by creating the largest performance decrement at the shortest SOA.

6.6.1 Method

6.6.1.1 Participants

27 (15 female) volunteers, age range from 18 to 24 (mean age = 20.2) were recruited from Cardiff University; their participation was in exchange for course credit. The data from three participants was excluded as their performance exceed pre-defined ceiling criterion (see General Methods).

6.6.1.2 Materials

All auditory samples were 115 ms in length. Targets came from two stimulus categories; either ‘Cod’, Cot’, ‘Nab’ or ‘Nap’, or ‘1’,’ 4’, ‘7’, or ‘10’. Target presentation order, as with Experiment 4, was fixed: if T1 was word, T2 was always a digit and vice versa. As with Experiment 6, the same changing, repeated and no distractor conditions were used. SOA’s and additional timing manipulations were the same as for Experiment 6.

6.6.1.3 Design

As Experiment 6.

6.6.1.4 Procedure

See General Methods section.

6.6.2 Results

The likelihoods of correct identification of T2 collapsed across distractor types for both attention conditions are presented in Figure 5.12.

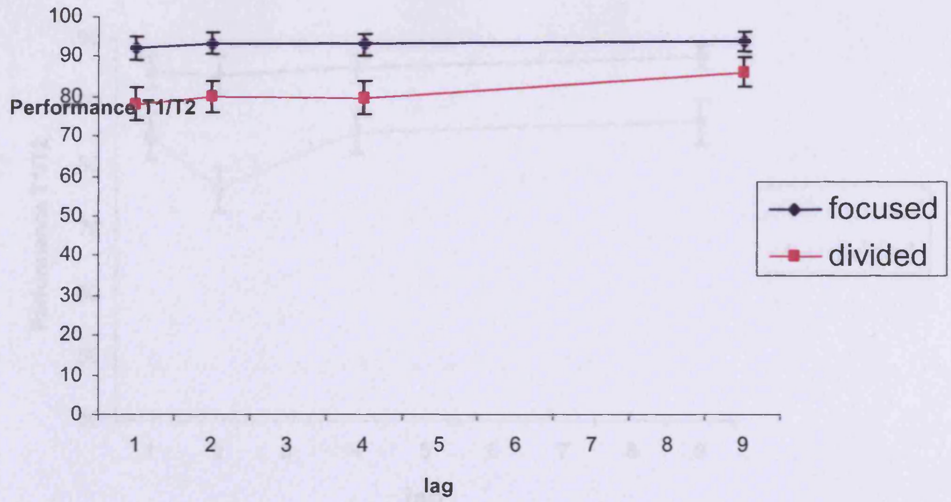

Figure 6.12 Overall performance collapsed across distractor type (error bars = +1/-1 mean standard error)

T1 performance: On average, T1 identity was reported correctly on 87% of the trials in the divided-attention condition. An ANOVA with condition (2 levels), distractor type (3 levels) and SOA (4 levels) as repeated-measure factors was carried out on the data. There were no significant differences in performance across conditions (all p's > .05).

T2 performance: Data was analysed using a 3 way repeated-measures ANOVA with attention (2 levels), distractor type (3 levels) and SOA (4 levels), and in keeping with the approach throughout this thesis using the conditional probability of accurate T2 identification given correct identification of T1. The analysis revealed a significant main effect of condition $F(1,23) = 19.483$, $mse = .193$, $p < .001$, distractor type $F(1.875,43.135) = 7.893$, $mse = .002$, $p < .001$, and SOA $F(2.618,60.209) = 7.002$, $mse = .002$ $p = .001$. These effects were modulated by significant interactions between attention and SOA $F(2.29,52.668) = 6.020$, $mse = .002$, $p < .005$, and distractor type and SOA $F(3.463,79.649) = 9.148$, $mse = .275$, $p < .001$, as well as an interaction between all three factors $F(3.958,91.024) = 5.488$, $mse = .002$, $p < .005$. These interaction terms licensed further analysis, which was carried out separately for each distractor condition.

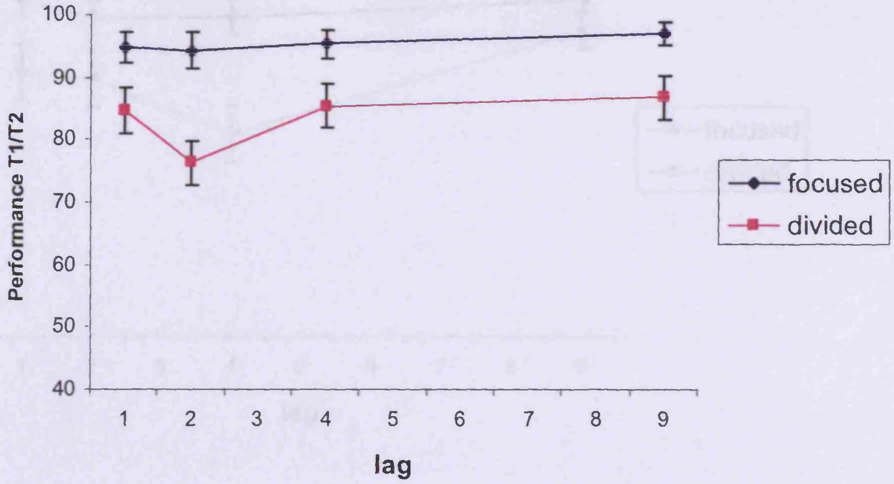

Figure 6.13: Performance for the no distractor condition (error bars = +1/-1 mean standard error)

Performance data for the no distractor condition (see Fig. 6.13) was submitted to an ANOVA with two repeated factors, attention (2 levels) and SOA (4 levels). The analysis revealed significant main effects for both attention $F(1,23) = 23.440$, $mse = .004$, $< .001$ and SOA $F(2.437,56.046) = 5.979$, $mse = .008$, $p < .005$, along with the interaction of these two $F(3,69) = 2.953$, $mse = .010$, $p < .05$. A planned comparison carried on performance at lag 1 and lag 2 across attention conditions revealed a significant difference $t(23) = -2.314$, (M = -7.865, SD = 16.651), $p < .05$, indicating that the difference in performance across the divided and focused conditions was reliably larger at lag 2 than at lag 1.

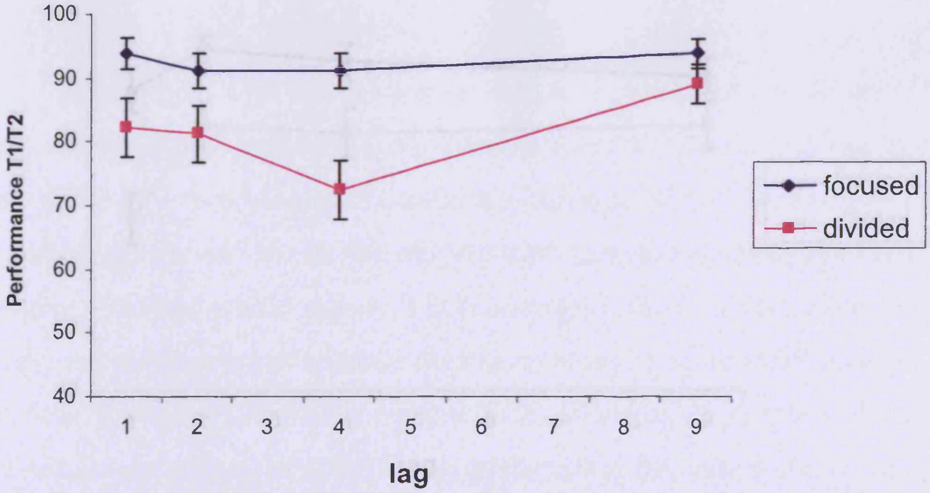

Figure 6.14: Performance for the repeated distractor condition (error bars = +1/-1 mean standard error)

Performance data for the repeated distractor condition (see Figure 6.14) was submitted to ANOVA with factors of attention (2 levels) and SOA (4 levels). The analysis revealed significant main effects for both attention $F(1,23) = 12.184$, $mse = .010$, $p < .005$ and SOA $F(2.320,53.356) = 6.267$, $mse = .003$, $p < .005$, along with the two-way interaction $F(2.446,56.260) = 7.431$, $mse = .001$, $p < 001$. The analysis of lag 1 sparing revealed no reliable differences across lags 1 and 2 ($p > .05$). Performance at lag 4, however, was lower than at all other lags: lag 1 vs. lag 4: $t(23) = -2.321$ (M = -9.115, SD = 19.239), $p < .05$; lag 2 vs. lag 4: $t(23) = -3.725$ (M = 8.855, SD = 11.645), $p < .005$ and lag 4 vs. 9: $t(23) = 4.856$ (M = 14.165, SD = 14.187), $p < .001$.

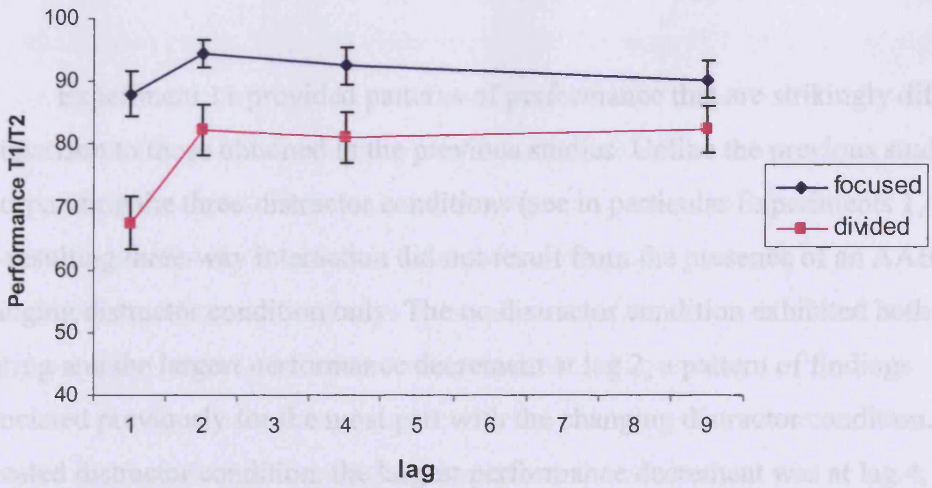

Figure 6.15: Performance for the changing distractor condition (error bars = +1/-1 mean standard error)

Performance for the changing distractor condition (see Figure 5.15) was again submitted to an ANOVA with the same factors as above. Significant main effects for both attention $F(1,23) = 16.822$, $mse = .009$, $p < .001$ and SOA $F(1.476,33.940) = 12.768$, $mse = .151$, $p < .001$, were accompanied by the interaction between these two $F(1.617,37.180) = 6.060$, $mse = .002$, $p < .01$. A planned comparison was carried out upon the data for lag 1 and lag 2 across attention conditions and revealed that the performance difference between conditions at lag 1 was greater than at lag 2 $t(23) = 2.241$, (M = -8.333, SD = 18.214), $p < .05$.

In summary, the three-way interaction that came about in the initial global analysis is because in the changing distractor condition the performance decrement in the divided condition relative to the focused condition decreased with lag. In the changing condition, the largest relative decrement was at lag 4, while in the no distractor condition the largest relative decrement was at lag 2.

6.6.3 Discussion

Experiment 11 provided patterns of performance that are strikingly different in comparison to those obtained in the previous studies. Unlike the previous studies incorporating the three-distractor conditions (see in particular Experiments 1, 2 and 4), the resulting three-way interaction did not result from the presence of an AAB in the changing distractor condition only. The no distractor condition exhibited both lag 1 sparing and the largest performance decrement at lag 2, a pattern of findings associated previously for the most part with the changing distractor condition. In the repeated distractor condition, the largest performance decrement was at lag 4, while in the changing condition T2 accuracy was lowest at lag 1. The principal difference between these studies and those described previously is the difference between T1 and T2 stimuli. It seems reasonable to assume that this change is likely to have imposed more of a switch cost here than in the previous studies.

The requirement to switch sets between T1 and T2 is considered to impose demands on the cognitive system (Visser, et al., 1999), and the common assumption is that switch costs will have greater impact at short than at long SOAs. The question is how to reconcile this account with the findings in this experiment. The only condition in which the performance profile is consistent with a switch cost account is the changing distractor condition, and in previous experiments, the changing distractor condition has yielded little evidence for an AAB.

Given this profile, it seems reasonable to consider whether streaming principles might offer an account of these findings, since the extent to which streaming is likely to occur is different in this experiment than in previous ones in which words in which consonant-vowel-consonant (c.v.c) word order only were employed.

In contrast to this, digits and words were inter-mixed in this experiment. Digits have different stimulus properties to the c.v.c targets, and in particular, their identity can be determined earlier: digits are distinguishable from each other prior to the final letter, unlike the c.v.c combinations (cod/cot, nab/nap). This difference may in principle be a contributor to the marked differences across experiments with regard to the differences between divided and focused attention conditions.

The no distractor condition allows an examination of an auditory context-free stimulus-set switch. The findings in this experiment contrast sharply with those described previously in this thesis, and with previous findings in the visual modality. In both of these cases, there has been no reliable AB when T1 +1 or T2 +1 items have been absent. Work in the visual modality conversely has described the attaining of a VAB without backward masking by implementing a task switch (Kawakawa, Zuvic, Enns & Di Lollo, 2003). However, these were only demonstrated with novel stimuli items (circles with line of a certain orientation, as apposed to letter or digits) and without lag 1 sparing, so it remains to be determined whether a VAB can be obtained with no distractors and a category switch in the visual domain.

The performance pattern for the repeated distractor condition again diverges from the findings in previous experiments (see in particular Exp. 4) The present study exhibited lag 1 and lag 2 sparing, with lag 4 performance at a similar level to that of lag 2 of Experiment 4, where there was not a comparable change between T1 and T2 stimulus sets.

The data from the changing distractor condition is distinctly different to that of Experiment 4, for the same condition. Performance at lag 1 is at its lowest, whereas throughout this thesis the changing distractor condition has constantly produced lag 1 sparing. Performance at all other lags is unaffected by SOA.

6.6.3.1 Comparative performance at lags 1 and 2

What the change in stimulus set seems to do is change the dynamics of target identification at the early lags. For the changing distractor condition performance with a change at lag 1 is at the same level when no change is implemented (8% difference at lag 1 between Exp. 4 & Exp. 11).This is not true at lag 2 (lag 2 = 60% for Exp. 4 & 83% for Exp. 11). Performance at lags 4 and 9 is very similar. For the no distractor condition performance at lags 2, 4 and 9 was very similar, but with a large difference at lag 1 (lag 1 = 71% for Exp. 4 & 84% for Exp. 11). Thus, the lag 2 effect with a switch is the same magnitude as performance at lag 2 with no switch. The repeated distractor condition shows a similar pattern as the no distractor condition. Performance at lag 2 with a switch again, is at a similar level when no switch is implemented (c. 74%). Therefore, the difference between experiments 4 and 11 is about the difference in performance at lags 1 and 2. The differences in performance at lags 1 and 2 appear to be diametrically opposed with the implementation of a switch. For the changing condition performance at lag 2 is higher with a switch, the repeated is higher with a switch at lag 1 and 2 and the no distractor is higher at lag 1.

6.7 General Discussion

The aim of the series was to understand further the processes underlying the AAB. In order to do this, switches were introduced across modalities in experiments 9a and 9b, between targets (task set: Experiment 10), and between categories (stimulus set: Experiment 11). The present series showed that the AB is not immune to switches across modality with no preparatory task switch, which opposes the view of Arnell and Larson (2002). In addition, the AAB is also not immune to a switch between target categories from T1 to T2. The switches can be distinguished by the difference between the target presentations; with no difference between targets (Exps 9 and 10) no AB is shown and with a difference between T1 and T2 (Exp 11) the AB is demonstrated. This implies that 'blinked' items within the auditory sequence are processed categorically, suggesting the locus of the AAB is at least partly postperceptual as with the VAB.

6.7.1 Cross modal interactions

Partial replication of Arnell and Larson's (2002) findings was achieved. One major difference across the two experiments was in the within visual condition in which typical behavioural patterns were not demonstrated (vis-vis conditions of Exp's 9A & 9B). One disparity between Experiment 9 and 10 and Arnell and Larson's (2002) study relates to Lag 1 sparing effects. Arnell and Larson demonstrated lag 1 sparing for all presentations of visual T2, however experiment 9B only demonstrated this effect in the auditory crossed modality conditions. This again questions the design of cross-modal investigations in general. If the modality of target presentation is blocked the participant will prepare for, direct attention, a particular target in a specific modality. In addition, this preparatory benefit will increase with exposure or practice. Therefore, if participants are expecting a change across modalities this expectancy could in turn lead to a behavioural pattern consistent to that of a task switch, even with no switch occurring. When the order of target presentation modality is randomised, an increased level of monitoring is required, which may increase the effect of the task switch by reducing the available processing resources. In both circumstances, with target modality either blocked or random, the phenomenological experience is very different to a single modality experiment. It is, in addition, difficult to control entirely for the possibility that different expectations with respect to modality of presentation may occur across participants as well as within participants during different trials or trial sequences of a task.

As to the crossed auditory condition (Fig 6.3 & 6.8), the patterns of results are very similar to both Experiments 9A and 10. This may be due to the speed at which processing occurs. If auditory T1 items are processed more expediently then the there would be less residual target information to cause interference T2 visual item presented at lag 1. The addition of visual distractor items (T2 at lag 3) causes interference, therefore reducing processing resources.

The data from the visual crossed condition of Experiment 9A demonstrated the lowest performance at the earliest two lags. If the visual attentional gate is sluggish (as in the description of lag 1 sparing within the visual literature), why is performance at the succeeding earliest lag for the auditory target (although this performance increases in experiment 2, probably due to the increased audibility)? If however the items were processed centrally, there should be an increase in performance with the increase in temporal distance between the target items. As this is not the case, it may be inferred that the auditory items are processed differently, (performance curve similar between Experiments 9A & 9B, just increased with audibility) as there seems to be no interaction between the two. If auditory items have the luxury of increased longevity in the echoic buffer then reconstruction of the items after presentation will be unaffected by SOA, or target number interaction.

From both the cross-modal experiments it would be hard to make firm conclusions as to the role of preparatory task set switching either endogenous or stimulus driven. In addition, Arnell and Larson (2002) stated that a certain number of participants were excluded from the analysis due to not attaining a certain level of performance. The present studies only utilised an exclusion criteria for very high levels of performance, for which no participant reached in Experiment 9A, 9B and 10.

6.7.2 Task switch

The four experiments within this empirical series have one factor in common; a switch or potential switch in either modality or stimulus set from T1 to T2. For comparison between experiments 9, 10, and experiment 11 the focus here is on the notion of stimulus set. Experiments 9 and 10 utilised a methodology that has been assumed to eliminate preparatory task switching, whereas the design of Experiment 11 meant that switching may have conferred some performance advantages. Switch costs should be largest at the earliest SOAs (Arnell & Larson, 2002; Pashler, 1999; Potter et al., 1998). The results obtained here highlight differences between the VAB and AAB. For lag 1 sparing to be shown for the VAB, no switch between T1 and T2 may occur (Visser et al., 1999). However, when this methodology is implemented in cross-modal investigations, no lag 1 sparing is demonstrated: performance is at its lowest at early SOAs. Similarly, implementing a large switch between T1 and T2 actually increases performance at the earliest SOAs (Exp. 11; see section 6.6.3.1 for overall description).

The incorporation of a degree of switching appears to be necessary to elicit the AAB. It would appear that for the AAB, increasing the relative saliency of T1 and T2 increases the likelihood of an interaction at some point within the processing stream. In fact, introducing a large switch between targets elicits the AAB effect even without any distractors. This is diametrically apposed to the VAB in which is it believed that similarity and backward masking causes the interference needed to elicit the AB.

Chapter 7

General Discussion

The broad aims of this thesis were to substantiate the existence of the auditory attentional blink (AAB) and to investigate the processes underpinning the AAB effect. In the experiments described above reliable AABs were obtained in certain conditions but not in others, the pattern of findings providing information relevant to the question of the appropriate theoretical explanation for the AAB. The starting point for this endeavour was the question of whether the principles held to be responsible for the visual AB could also explain the conditions under which AABs occur. There have been no systematic analyses to date of the correspondence between the visual and the auditory attentional blink. The findings suggest that the same set of principles cannot explain satisfactorily the visual attentional blink (VAB) and the AAB. In broad terns, the findings in this thesis counter strongly one existing claim, which is that the AB is purely a visual phenomenon (Potter et al., 1998). The findings presented here suggest that considerations of perceptual organisation (Bregman, 1990) are a viable means of explaining at least some AAB phenomena. In a later section, the question of whether considerations of perceptual organisation can also explain the VAB will be entertained. First, however, a brief summary of the principal findings in this thesis is provided.

7.1 Experimental findings

7.1.1 Overview

As with the VAB, the main manipulation utilised for all the empirical work of this thesis was T1-T2 SOA, the number if items intervening the two targets. The AAB was characterised by a significantly larger difference in target identification at lag 2 than at lag 1 for the divided attention condition (requiring the correct identification of both targets) compared to the focused attention condition (requiring only the second target identification). As with the VAB, the AAB requires non-target, or distractor items *in most circumstances*. By contrast, the order of the distractors is very important for the AAB, whereas the VAB requires a random order of distractors to maximise backward masking. An ordered context was needed to produce the AAB (e.g. Experiments 2 & 4): the repetition of a single unit was not enough but repetition of a changing three-distractor sequence produced the AAB.

7.1.1.1 Context

The initial experiment within the empirical series was a replication of Experiment 2 of Tremblay et al. (2005). Experiment 1 was not an exact replication, although the rapid auditory presentation (RAP) method and stimulus identities were the same novel stimuli and the same stimulus lengths were used. The purpose was two-fold. First, to provide more evidence for the existence of the AAB, and second to provide a stable test-bed for examining the temporal constraints of auditory attention. Experiment 1 presented targets in a fixed order in differing contexts; no distractors, repeated ('guh') and changing (repetition of 'guh', 'gih' and 'gah'). Experiment 1 did show very similar processing deficits to those reported by Tremblay et al. (2005), in that there were lag-specific performance decrements for both distractor present conditions. Participants were more likely to identify both targets correctly when presented within a context if the targets were temporally adjacent than when one distractor intervened between T1 and T2 ('lag 1 sparing', Chun & Potter, 1995).

Experiment 2 examined the role of the context further. The previous experiment demonstrated that a context was required to elicit the AAB. However, an important question is whether the context is required to provide cues to orient attentional focus. On the other hand, the context may restrict processing allocation by introducing more interference within the perceptual store by either masking the targets, or allowing more complete segregation of target information. Participants were required to correctly identify targets presented in repeated, changing or random ('gah', 'geh', 'gih', 'goh' & 'guh': 5 items were required to provided sufficient randomisation) distractor sequences. The AAB decrement was demonstrated for the changing distractor condition only. The results demonstrate that merely presenting distractors before and after targets is not sufficient to elicit the AAB; the order of the distractors is important.

7.1.1.2 Pre-T1 items

The third experiment focused upon the items presented before T1: the *pre-T1 items*. The motivation arose from the issue of whether a masking or streaming account is required to explain the AAB. The masking account would assume that the items of interest occur after the target, whereas a streaming account would rely also on the items occurring before the target. As the previous two experiments had demonstrated reliable AABs with the changing distractor this condition was employed in Experiment 3. The number of pre-T1 items was manipulated, and there were either zero, three or six items. It was shown that, as with the previous two experiments, six pre-T1 items (or two repetitions of the 3-item distractor sequence) are required to elicit lag 1 sparing and the recovery at lag 9. In addition, no T1-T2 interaction was shown for both the zero and three pre-T1 item conditions. The results suggest a 'window of opportunity' for the AAB.

Experiment 6 expanded upon the findings of Experiment 3 by increasing participants' exposure to pre-T1 items. Either T1 was presented as the first item in the stimulus stream or followed nine or 18 items of the changing distractor sequence. Performance for the zero pre-T1 condition replicated that of Experiment 3: no AAB was evident. The presentation of nine or 18 pre-T1 items did not elicit any AAB like performance decrements and overall performance was reduced for all conditions.

7.1.1.3 Participant performance and the stimulus presentation rate

One important aspect of Experiments 1, 2 and 3 was that over 70% of participant's performance on the tasks above 92% in all conditions. Although similar patterns of results were obtained in the first three experiments, it is arguably hard to generalise these patterns with so many participants excluded from the analysis. Therefore, Experiments 4 and 5 increased the stimulus presentation rate (SPR) which in turn increased the difficulty and reduced the numbers of excluded participants. Experiments 4 and 5 replicated the findings of Experiment 1 and 3, except for the repeated distractor condition, which did not show a significant SOA interaction.

7.1.1.4 The effects of practice

Experiments 7A and 7B investigated the influence of practice upon the AAB. The impact of practice on the visual AB has not received any attention. Participants were exposed to 48 practice trials consisting of either the two targets, sequences from the no distractor condition (Exp. 7A) or the sequences for the repeated distractor condition (Exp. 7B). Increasing exposure to the targets only during the practice session produced a slightly attenuated AAB for the changing distractor condition. However, exposing participants to the repeated distractor sequence during practice eliminated all SOA dependent performance deficits.

7.1.1.5 Target-distractor relationship

The target-distractor (T-D) relationship was investigated in Experiments 8A, 8B and 8C by manipulating the stimulus set of targets and distractors. Stimulus sets utilised were either letters or digits. Letter targets were 'K', 'L', 'R' and 'Y' and digit targets were '1', '4', '7' and '10'. Due to the application of single letters or digits, a shorter SOA of 100 ms was used. In addition, a pure tone of 50 Hz was presented concurrently with the targets to increase target saliency (a technique adopted from the cross-modal AB work of Karen Arnell and colleagues). The distractor sequences were either repeated (repetition of a single unit) or changing (repetition of a three-unit sequence). SOA specific performance decrements were demonstrated when both targets and distractors originated from the same stimulus set; letters targets presented within letter distractors (Exp. 8A) and digit targets within digit distractors (Exp. 8B). Interestingly for both Experiments 8A and 8B the decrement occurred at a later point, lag 4. However, when targets and distractors stem from different stimulus sets there was no reliable AB (Exp. 8C).

7.1.1.6 Presenting targets in different modalities

A series of experiments (Exps. 9A & 9B) investigated participants' ability to identify two targets when presented in the same modality, either visually or aurally, or across both modalities. As with Experiment 8A, letter targets ('K', 'L', 'R' and 'Y') and distractors were used as well as the presentation of a concurrent tone with each target. The design of experiments 9A, 9B and 10 was the same as that used by Arnell and Larson (2002) whereby target identity or modality of T1 did not predict the identity or modality of T2. Additionally, the auditory stimuli for Experiment 9A were the same as those used by Arnell and Larson (2002) (delivered in a North American accent) whereas the auditory material for Experiments 9B and 10 were recorded locally (a native UK accent). Experiment 9A did not replicate the findings of Arnell and Larson in that only within modality ABs were demonstrated. However, Experiment 9B did produce both within and across modal ABs as well as replicating the lag 1 sparing for the auditory crossed condition of Arnell and Larson. Experiment 10 presented the same auditory material as Experiment 9B in the auditory modality only and demonstrated the same pattern of performance as the auditory only condition of Experiment 9B.

7.1.1.7 Presenting targets from different stimulus sets

Experiment 11 utilised the no distractor, changing and repeated distractor sequences of previous experiments with an SOA of 115 ms. The targets were derived from two different stimulus sets: either; ‘cod’, ‘cot’, ‘nab’ ‘nap’ or ‘1’, ‘4’, ‘7’, or ’10’ where T1 (e.g. cod) differed to T2 (e.g. 4). T1 could be one from the four of the set with each having an equally likelihood of occurring. Different SOA specific decrements were produced for each distractor condition; a lag 2 decrement (described as the AAB in this thesis) was shown for the no distractor condition, a lag 4 decrement for the repeated distractor condition and a lag 1 decrement for the changing distractor condition.

7.1.1.8 T1 performance

Throughout the empirical series, performance for T1 demonstrated a degree of variation. This variation does have a direct impact upon the calculation of performance for T2. Performance for the divided attention condition is calculated as a conditional probability of T2 being correct given the correct identification of T1. Therefore, the more instances in which T1 is given as incorrect, the less trials there are in the critical T2 analyses. However, T1 performance across experiments was broadly high (between 80 % and 90% correct with the exception of the replication of Arnell & Larson, 2002). This level of performance is similar to that reported by Tremblay et al., (2005), as well as being similar to the levels reported in many visual AB studies (Chun et al., 1998, Chun and Potter, 1995; Raymond et al., 1992; 1994).

7.1.3 Context: Presence versus Absence

The presentation of the target items, either within or without a context, highlighted large performance differences at lag 1 (Experiments 1 & 4). The distractor present conditions demonstrate an AAB curve, the no distractor condition produces a linear improvement in performance as the number of distractors, between the two targets increased. The influence of the context must, in someway alter the way in which the information is captured and its subsequent processing. With the exposure to a regular sequence, as with the distractor-present conditions, the likelihood of correct anticipation of target onset is increased (Bregman, 1990). An increase in anticipation relates to the ability of the attentional system to focus on a certain temporal point. This compares well to the abolition of lag 1 sparing in the visual AB with a switch in spatial location. Therefore, for the AAB, presenting the targets within a context increases the chance that targets are captured as a similar event, within the same attentional window.

Differences between the distractor conditions however, may reflect the variation in processing demands upon the attentional system. The distractor conditions differ by the number of streams created; one for the repeated distractor and three for the changing distractor condition. The AAB has been consistently demonstrated when the targets are presented within the changing distractor context (for both an SPR of 7.69 & 8.69 items/s). Through the creation of more streams, more knowledge about the order within the sequence is available to the listener. The changing-state of the TBI field allows greater integration into a more coherent mental representation (Bregman, 1990). The manipulation of the number of pre-T1 items (Experiments 4 & 5) illustrated this, as lag 1 sparing only occurred with six pre-T1 items. The knowledge of the regularity within the sequence requires the building up of a representation of the regularity in the context. However, over exposure to the sequence (Experiment 6) reduces the performance at lag 1. One possible explanation for this may relate to the exposure the sub-streams; with more exposure, the sub-streams move apart from each other, in a sense they become disassociated. The creation of stable streams reduces the change experienced by the listener. Therefore, one stream (e.g. 'guh') out of the three may become the point of focus and as the one distractor item occurs once every three items.

7.1.4 Context: Ordered versus Random

One methodological difference between the auditory studies described in the present work and the abundance of visual AB literature is the order in which the distractors are presented. As previously stated the random order of the distractors is vital for the visual modality, to mask the items within the RSVP effectively (Enns, 2001). However, the role of masking differs for the auditory modality due to the nature of the perceptual system. If the properties of the items within the sequence are in a repetitive order items sharing the same acoustical properties will group together to form sub-streams. Therefore, the masking +1 items will group with the other distractors reducing their masking potential. However, performance data from the random distractor condition (Exps. 2 & 10) shows a similar pattern to that produced by the no distractor conditions. Therefore, merely presenting post target items does not fully explain the results. Through imparting order into the context, the targets are more likely to be considered similar, hence both targets being captured when presented contiguously. Presenting a random context removes predictability.. Due to the lack of predictability across the whole sequence each item is scanned more intently thus increasing the workload upon the attentional system. As each item has to be processed individually the targets therefore are not considered similar and therefore will not be captured within the same attentional episode, hence the removal of lag 1 sparing.

7.1.5 Modality interactions

The existence or otherwise of a cross-modal AB is a controversial topic (Arnell & Jenkins, 2004; Arnell & Jolicoeur, 1999; Arnell & Larson, 2002; Potter et al., 1998). Consistent evidence has been produced support for modality independent theories of the AB suggesting limits on stimulus consolidation in amodal memory stores (Arnell & Jolicoeur, 1999; Arnell & Jenkins, 2004; Arnell & Larson, 2002; Jolicoeur, 1998, 1999). However, experimentation into the cross-modal AB has generated a pattern of mixed results. It has been suggested that a cross-modal AB would be exhibited when the tasks for T1 and T2 were different; in a sense, the pattern of performance was merely reconfiguration cost artefact (Potter et al., 1998). Research outside of the AB literature has demonstrated substantial reconfiguration costs arising from a similarly predictable task switch as that of Arnell and Jolicoeur (1999) (whereby the task for T1 and T2 were fixed across trials) (Allport et al, 1995; Rogers & Monsell, 1995). To answer this concern, Arnell and Larson (2002) developed a paradigm in which the task demands for T1 and T2 were the same, the identification of one of four letters. The order in which the target letters were presented was random.

Arnell and Larson (2002) reported auditory crossed (auditory T1 – visual T2) ABs with lag 1 sparing, the replication in this thesis (Experiments 9B), however demonstrated with a local accent. As with Arnell and Larson, Experiments 9 and 10 demonstrated a high level of performance when T2 was presented directly after T1; however, performance did not improve as the number of items interpolated between the two targets increased. In fact, the auditory-crossed condition was the only condition that exhibited lag 1 sparing. The fact that there was no recovery suggests that performance at lag 1 may not represent the dual encoding of both targets within the same amodal resource but may highlight the fact that two different systems are at work. The switch from the auditory to visual modality requires time to refocus attention from one location to another (Posner, 1980). The elevated performance for a visual T2 at lag 1 may result from the fact that the participant has their foveal focus upon the screen with whilst the auditory information is being presented. After the auditory presentation, T2 is the first visual item therefore, as the initial item has no interference. As more items are presented visually (performance when T2 is at lag 3, 5, 7, 9) more interference is created demonstrated by the low performance.

7.1.6 Stimulus presentation rate

The visual AB paradigm uses alphanumeric stimuli and an SPR of around 10 items/s, although visual items are presented for a shorter period with a blank ISI between items. The use of shorter stimuli, letters rather than c.v.c items in the presented investigation produced an interesting set of results in relation to lag 1 sparing (Experiments 8A & 8B). The consistent finding was that performance for T2 at lag 1 and lag 2 was very high. Arnell and Jolicoeur (1999) demonstrated a similar pattern of performance for the auditory within condition of a cross-modal study. The stimulus type (letters) and SPR (9.52 items/s) were very similar to Experiments 8A and 8B. The typical performance curve from the work in the visual AB shows a dramatic drop in performance when the targets are serially separated one distractor. The reason that lag 1 sparing only occurs for items at lag 1 is hypothesised to related to the amount of information entering the attentional system due to the sluggish closing of the attentional gate. This may also relate to the amount of information afforded space in the iconic buffer. Therefore the results from Experiments 8A and 8B, may also relate to the amount of information within a T1 epoch. It would suggest that in line with previous research concerning auditory stores (Cowan, 1984) that auditory perceptual representations have an increased longevity. The finding of lag 1 and 2 sparing may represent an informational rather than a temporal limitation that is only highlighted in the auditory domain due to a larger memorial capacity for perceptual information.

7.1.7 Imposing a categorical criterion-shift

Featural or categorical similarities between targets and distractors have been shown to affect the size of the AB for visually presented stimuli (Chun & Potter, 1995; Raymond et al., 1995). This modulation was hypothesised to arise from the distractor set influencing a threshold criterion initiating its consolidation. The more similar the distractors are to the targets (letters versus digits) the more confusion in the VSTM thus producing a larger AB (Shapiro, 2001). Interestingly, presenting a +1 item of a similar stimulus category, e.g. a letter target followed by a letter +1 item creates a larger AB than if a dot pattern of similar spatial frequency follows the target (Raymond et al., 1995). As previously stated, the AB has thought to arise from the specific nature of the VSTM. Until the publication from Tremblay et al. 2005, this was considered the case as no auditory or cross-modal study had reliably demonstrated lag 1 sparing. It could be said that the paradigm of Tremblay et al. suggest that the AB may not be purely a visual phenomenon. Therefore one may assume that auditory materials are conceptually (words vs. non-words) and acoustically (distractors have plosive offset whereas targets have fricative offsets) different.

7.1.8 Switching task demands between targets.

All target search tasks are defined by the perceptual nature of the target, so a task switch refers to a switch in perceptual set from one target to another (Chun & Potter, 2001). Therefore, switching the category that define the targets, e.g. from a letter to a digit will involve a task switch. A task switch from T1 to T2 may produce an artefactual effect that may mirror the AB effect (Potter et al., 1998) and has been used to explain the AB 'like' performance for cross-modal studies. Performance for T2 will gradually improve with increasing SOA due to the reduction in the dual-task interference imposed by the processing of T1. From Experiment 11, which employed a task switch between from T1 to T2, the context had a dramatic affect upon target identification. At early SOAs, performance appears to be improved. The changing distractor did not elicit lag 1 sparing whereas the no and repeated distractor conditions did. From pervious experimentation, the changing distractor condition was the only condition that produced a reliable AAB effect. Therefore, if the changing distractor condition demonstrated the AAB through the restriction of processing resources, as with the visual AB, and then the pattern of data produced in Experiment 11 was expected. The reconfiguration of cost is at its highest then T2 is presented directly after T1. This affect then dissipates after lag 1 with subsequent performance unaffected.

The data form the no distractor condition replicates the findings of Vachon and Tremblay (personal communication, Dec 2004) where a switch (pitch-shift) between T1 and T2 exhibited lag 1 sparing. This finding appears to be strange in relation to all other reasoning about a task switch and the AB. The way in which the targets are perceived has changed in relation to Experiments 1 and 4, which demonstrated a monotonic function of T2 performance across lag. When a task switch is employed between targets without a context lag 1 sparing has been demonstrated. With the visual AB lag 1 sparing is reliant on the degree on similarity between the targets, the more similar, the larger the lag 1 sparing.

The data from Experiment 11 suggests that the difference may be a factor. From Chapters 3 and 4, the use of targets pairs of 'cod/cot' and 'nab/nap' demonstrated lag 1 sparing, which suggests that the targets are similar enough to be considered as origination from the same perceptual set. The pattern of data from Experiments 1 and 4 for the no distractor condition, may relate to the attentional capture mechanism. This would suggest that the auditory attentional capture is more likely to identify change, rather than similarity. As for the changing distractor condition, the reason why lag 1 sparing occurs is that the distractor modulation created an environment of change. Therefore, with no distractor the target pair (Exp. 1 & 7) are considered similar thus decreasing identification. Due to the lack spatial restrictions on the auditory domain, it has been considered an 'early warning system' (e.g., Scharf, 1998) therefore relying more on changes within the environment (Dalton & Lavie, 2004).

In conclusion, the pattern of data from Experiments 4, 10 and 11 allows comparison between the cost, and benefit of imposing a switch between targets at short SOAs. Experiment 10 was designed to reduce preparatory switch costs, and in doing so removed all likelihood that T1 would predict the identity of T2. Experiments 4 and 11 used stimulus sets in which T1 would predict the identity of T2, however, the difference between T1 and T2 is much greater in experiment 11. Increasing the difference between T1 and T2 coupled with a predictable switch increases performance at the earliest lags.

7.2 Masking versus streaming

For clarification as to which concept - either masking or streaming – provides the most complete account of the phenomena in question, comparison between the ordered and non-ordered context is required. Masking of both the targets has proved to be vital for the production of the visual AB (Enns, et al., 2001; Shapiro et al., 1994). Masking is assumed to act to reduce the allocation of processing resources for the targets by creating interference in both perceptual and post-perceptual processing units. For T1, either integration or interruption masking produces the AB, whereas the more sensitive nature of T2 requires only interruption masking (Enns et al., 2001). The nature of the RSVP inherently masks each sequential item when presented in the same spatial location. The removal of the + 1 items eliminates the AB (Raymond et al., 1994), whereas a skeletal RSVP (only the targets and the +1 items) exhibits a traditional T1-T2 SOA interaction (Ward et al., 1997). However, auditory items are not as sensitive to backward masking (Arnell & Jenkins, 2004) as the removal of the T1 +1 item had no impact on the AAB magnitude (Mondor, 1998). In addition, an auditory T2 on the other hand does require masking, although is insensitive as to what type: any mask will do (Vachon & Tremblay, personal communication, Dec 2004[7]).

As previously stated, from a streaming perspective the behaviour of items within the sequence is affected by the degrees of similarity between items. Therefore using an ordered context changes the way the distractor items are perceived. The more similar the items, the more likely that sub-streams will form whereby those similar (or the same) items will group together to form a separate perceptual object. The properties of the +1 item will therefore be governed by the degree of their similarity to the other distractor items. If the +1 items are grouped within the resultant sub-streams, they will have a reduced masking effect. In relation to the visual AB, the idea of using repeating distractor items would be redundant as the visual system is more sensitive to changes over space.

The comparison between ordered (repeated and changing) and non-ordered (random) context will demonstrate the differences between masking and streaming. If,

[5] Vachon and Tremblay utilised a RAP paradigm similar to that of Mondor (1998) of pure tones and random distractors

as with the visual AB, the concept of masking were as vital, then the AAB would be exhibited when a distractor was presented contiguously after the target irrespective of the nature of the context. Whereas, for the concept of streaming to be able to explain the data then the AAB would be sensitive to perceptual organisation of items within the sequence. Therefore, the structure of the distractors would modulate performance thus affecting the AAB. The data from the empirical series would suggest that the structure of the context is very important for the production of the AAB, whereby the removal of order eliminated the effect. Additionally, exposure to the context modulates the AAB, suggesting that the items before the target are important, as opposed to the items occurring after the targets as with backward masking.

7.3 Attentional networks and the visual AB

Neuroimaging and patient investigations of the visual AB have identified the main cortical structures involved during visual AB tasks. These areas fall for the most part within the network of regions that are important for the control of visuospatial attention (see Figure 7.1 Corbetta, Kincade, Ollinger et al., 2000; Marois, Chun & Gore, 2000; Nobre, Sebestyn, Gitelman, et al., 1997). Briefly, the occipital lobe is involved with the initial registration of visual stimuli. Higher level aspects of visual processing are performed in infero-temporal cortex, which is also important, in combination with parietal cortices, for target detection. The posterior-parietal cortex is involved in target selection and stimulus identification, notably for familiar stimuli (Hommel, Kessler, Schmitz et al., 2005). The right posterior parietal cortex has been associated with the process of assigning task relevance to stimuli (Goldberg, Bisley, Powell et al., 2002). Moreover, it has been suggested that the more ventral areas of the posterior parietal cortex are implicated in the top-down control of stimulus processing and target identification (Corbetta, et al., 2000; Hommel et al., 2005). In particular, the posterior parietal correct may influence selection between competing stimulus representations in infero-temporalcortex (Hommel et al., 2005). Finally, lateral frontal cortex provides goal-directed and presumably top-down inputs within this attentional network. For example, and of particular relevance here, frontal cortex has been implicated in the control of multiple task performance, particularly with temporally overlapping tasks (Richer & Lepage, 1996).

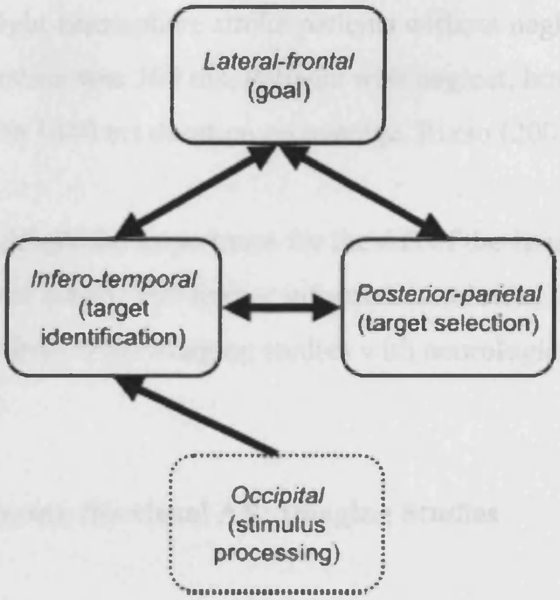

Figure 7.1: Structure and function in the visual attention processing network (taken from Hommel et al., 2005)

7.3.1 Neural activity during the visual AB: Patient Studies

Visual neglect results typically from acute cerebral lesions in the right hemisphere, commonly after stroke. This syndrome manifests as an inability to detect people or objects in the contralesional visual field. Although visual hemineglect generated a great deal of interest, the exact mechanisms underpinning the syndrome are unknown. The predominant theory describes a bias in responding to items to the right (Kinsbourne, 1970). An alternative, however, is an inability of the patient to disengage attention from stimuli in one visual field when required to make a shift to the other (Posner, Walker, Friedrich & Rafal 1984, 1987). Visual neglect is often referred to as a decrement in spatial awareness. However, utilising the VAB paradigm, investigations of limitations in temporal processing have also been carried out (Husain et al., 1997; Rizzo, 2001), certainly suggesting a problem with disengagement, but one that is not restricted to the spatial domain.

Husain et al (1997) examined right-hemisphere stroke patients with and without neglect, and compared them with non-stroke controls. Participants presenting with visual neglect had lesions in the right inferior parietal lobe and the right inferior frontal lobe. Both sites are commonly associated with neglect symptoms (Halligan, Fink, Marshall & Vallar, 2003). Eight subjects with right hemisphere lesions (superior parietal, temporal lobe, medial lobe, or subcortical regions) and no evidence of neglect were the controls. For right-hemisphere stroke patients without neglect and for control participants, the AB duration was 360 ms. Patients with neglect, however, demonstrated an AB with 1440 ms duration on average. Rizzo (2001) has reported comparable results.

These findings highlight the importance for the AB of the functional integrity of the right posterior-parietal cortex, and further information relevant to the role played by this region has come from brain imaging studies with neurologically intact participants.

7.3.2 Neural activity during the visual AB: Imaging Studies

EEG and MEG studies have contributed to an understanding of functional aspects of the visual AB. They have contributed little, however, to an understanding of the brain regions that are engaged during AB tasks (although for some speculations, see Kessler et al, 2005, Gross et al. 2004). In two fMRI studies, Marois and colleagues explored the neural network involved in the visual AB. In the first of these (Marois et al. 2000), they examined the neural activity elicited by T1, and found that when interference was high (accomplished by a manipulation of the distractors) there was greater activation in right posterior-parietal cortex (intraparietal sulcus) and lateral frontal cortex than when interference was low. Because the AB was larger in the high than in the low interference condition, they identified activation in these regions as being an important determinant of the visual AB. In this regard, the activation in posterior-parietal cortex is consistent with findings of visual AB deficits in neglect patients with damage to the right hemisphere (Husain et al., 1997).

In a second study, Marois et al. investigated the neural activity elicited by T2, and contrasted the activity associated with correct versus incorrect T2 judgments. The task involved identification of a face (T1) and a scene (T2), with distractors comprising scrambled faces and scenes. There were different patterns of neural activity in three regions. In the parahippocampal place area (associated with higher-level visual processing), activity for correct T2 judgments was greater that for incorrect T2 judgments, which was greater than that for distractors in the same serial position. This finding is consistent with behavioural (Shapiro et al, 1997, priming study) and electrophysiological evidence (Luck & Vogel, 1997) that 'blinked' stimuli are still processed to a relatively high level, although no reported consciously. In the intraparietal sulcus, activation was equivalent for correct and incorrect T2 judgments, but both differed from comparable distractors. The authors suggested that this pattern of activation suggests that the intraparietal sulcus is involved during the AB in resolving perceptual interference that is necessary for any trial on which a target appears. Finally, the lateral frontal cortex was engaged to a greater degree for correct T2 judgments than for the other two classes of task item. This suggests a specific role for this anterior region in target processing.

All of these regions form part of the 'attentional network' and it is arguably unsurprising that these regions are engaged during AB tasks. How much these findings say specifically about the neural basis of the AB is, however, difficult to ascertain, as Marois et al. (2004) failed to observe lag- 1 sparing. In their earlier study, furthermore, the task completed in the scanner did not require T2 judgments, so their findings and conclusions concerning T1 processing hold only if it assumed that T1 processing when there is no requirement to process T2 is comparable to the processing that occurs when T2 processing is also required. There is no fMRI data to date for the auditory AB, but in so far as the posterior-parietal and lateral frontal cortices form part of a general attention network, activation in those regions during AB tasks would be predicted. Making predictions about regions responsive to higher-level processing of the auditory stimuli is less straightforward.

7.4 Perceptual load

The existence of mechanisms for selection during mental processing has been an accepted fact for over half a century. The locus of that selection, however, has proved a source of much debate (see section 1.1.2 for a review of early theories). Kahneman and Treisman (1984) suggested that the experiments demonstrating an early locus of selection were more complex than the more modern demonstrations of a later locus of selection. They suggested that the two approaches might recruit different attentional mechanisms (Kahneman & Treisman, 1984). This notion was developed further by Lavie (1994), among others, who suggested that perceptual load was the main determinant for when selection occurs.

A late locus of selection has been determined for the visual AB (Shapiro, 2001; Shapiro et al., 1995), suggesting a relatively low load upon perceptual processing (or at least a load that does not exceed capacity). Increasing the demands upon the perceptual system, such as superimposing the +1 item over T2 (Giesbrecht & Di Lollo, 1998), eliminates the effect. In addition, removing the +1 item also eliminates the effect (Raymond et al., 1992).

Both the Two-stage (Chun & Potter, 1995) and Interference (Raymond et al., 1992; 1994) models do not speak directly to the notion of perceptual load, only that late selection is roughly correct (Shapiro, 2001). Is there a reasonable way, however, to consider the findings in the empirical series in this thesis alongside the notion of perceptual load?

The auditory AB was demonstrated within an ordered context (changing as opposed to random). Under these circumstances, the distractors have a high level of cohesion. The acoustic similarities between the repeated and changing distractors promote stream formation that in turn increases the distinctiveness of the targets. However, if the targets are too distinct, as in the case of the repeated (or no distractor) condition, the information is too easily extracted and no AB is demonstrated. That is, there is insufficient perceptual load. Conversely, if the targets are not distinct enough, the perceptual load is higher and the AB is abolished. This was demonstrated with manipulations of the context; the presentation of a random distractor sequence (Exp 2 and 10) or without the 'building up' (Carlyon et al., 2001) of the context, with three or less distractor items before T1 (Exp. 3 and 5). It seems, therefore, that one way of conceptualising the conditions under which the auditory AB occurs is with respect to the notion of perceptual load in the auditory domain.

7.5 A theoretical model for the AAB

The two-stage model proposed by Chun and Potter (1995) has gained a great deal of support from behavioural (Chun & Potter, 1995; Giesbrecht & Di Lollo, 1998; Visser et al., 1999) as well as electrophysiological (Sergent et al., 2005; Shapiro et al., 2006; Luck & Vogel, 1998; Vogel et al., 1999) and neuroimaging studies (Kessler et al., 2005; Marcantoni et al., 2003; Marois et al., 2000; Marois et al., 2004). The assumptions underlying this model have been outlined in previous sections. At issue here is the question of whether it provides an adequate explanation for the auditory attentional blink.

As described previously, there are broad correspondences between the circumstances under which the AAB and the VAB are elicited. One relatively straightforward means, therefore, of amalgamating the AAB within the two-stage model is to assume that it applies in general, but with somewhat different explanations associated with the influence of streaming versus the influence of masking. These explanations, however, can be assumed to apply prior to either processing stage in the two-stage model, because they relate specifically to the way in which targets are defined by the properties of the distracters.

There remain, however, several findings for the VAB that it will be important to develop for the AAB before a theoretical framework can be developed within any degree of confidence. One question concerns the fate of 'blinked' stimuli. In the visual domain there is behavioural as well as electrophysiological, and perhaps fMRI, evidence that 'blinked' items are processed to the level of their meaning. There is to date no comparable demonstration for the auditory domain. Similarly, the ERP evidence that early visual evoked potentials do not differentiate correctly identified from 'blinked' items has no auditory analogue to date. The earliest modulation in the ERPs that distinguished correctly identified from 'blinked' items was the P300. It remains to be determined whether that is true when auditory stimuli are employed. The extent, therefore, to which a purely post-perceptual theoretical framework for the AAB can be offered is one that awaits the outcome of further empirical investigations.

7.6 Future directions

From the data this one explanation and is however not able to contribute to significant theoretical development. Additional experimentation would be required to create a more concrete understanding to the cognitive processes at work. The use of electrophysiological methods such as event related potentials (ERPs) would be one way in which to decipher the true cognitive impact of the AAB. ERPs consist of a sequence of peeks and troughs representing positive and negative voltage deflections. The initial electrical signals relate to sensory processes and the later signals reflect progressively higher-level cognitive functions (Luck & Vogel, 2001). ERPs are elicited form stimuli that do not require a response allowing measurement to stimuli that participants fail to detect. Therefore, deviations in the electrical signal from the processing of different stimuli allow interpretations that are more conclusive to be made.

The work carried out by Vogel et al. (1998) highlighted the processing events during the visual AB extremely well. Through the examination of electrical deviations from 'normal' processing, Vogel et al. (1998) were able to determine that the 'blinked' item received semantic and categorical processing (see section 1.7.5 for a full explanation of procedure). The AB represented the suppressing of conscious representation hence the decrement in recall performance. A similar style of investigation would be required within the auditory domain to establish the fate of T2 during the period of decreased performance. This approach may be able to confirm the locus of the processing deficit described within this thesis, either at a perceptual and quite early level as predicted by Experiments 1 – 7, or at a later, semantic level as described by Experiments 8 and 11.

One methodological similarity between the standard VAB methodology and that of the adopted stimulus presentation technique described in this thesis related to pre-T1 items. As previously mentioned, (see section 7.1.1.8) the topic of pre-T1 items of the visual paradigm received no distinct analysis. Therefore, one immediate avenue for understanding the role of pre-T1 item within the VAB would be to carry out a VAB experiment and analyses performance in relation to number to pre-T1 items. In addition, a similar analysis could be carried upon a cross-modal AB experiment to understand the impact of pre-T1 item exposure upon switches in target modality.

The present empirical work has examined the influence of exposure to pre-T1 item and the resulting variation in target identification. However, it is felt that further experimentation would be warranted. Experiment 6 utilised 0, 9 or 18 pre-T1 items however without implementing a 6 pre-T1 item condition to provide adequate comparison. If a similar performance (a decreased level of target identification at lag 2, compared to lag 1 for the divided attention condition) with 6 pre-T1 items as Experiments 1, 3, 4 and 5 is demonstrated then firmer assumption concerning the build up of streaming factors may be afforded.

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Appendices

Appendix 1

None of the published studies in both the visual, auditory modalities has mentioned an exclusion rate, or participants performing at a consistently high level. The previous chapter utilised an SPR of 7.69 items/s, and only showed AB effects less than half of participants. Therefore, the present experiment examines further the role of the SPR and the AAB. The experimental manipulations of the previous chapter were unable to bring performance in to a measurable range, as the SPR was too slow; a more challenging SPR was required. Arnell and Jolicoeur (1995, 1999) have demonstrated robust effects for within and across the auditory modality utilising an SPR of 10.72 items/s, the same rate as used for the visual modality. Therefore, the present experiment increased the SPR to 10 items/s. From the previous chapter, other than the very high level of performance, the most consistent finding was the production of AAB like decrements using the changing distractor. The present experiment used the changing distractor with either three or six pre-T1 items. From the previous chapter large differences were shown between 3 and 6 pre-T1 items therefore if the increased SPR allows manipulation of perceptual factors this simple difference should modulate behaviour.

Method

Participants

17 (12 female) volunteers, age range from 18 to 26 (mean age = 19.2) were recruited from Cardiff University; they received a small honorarium for participating in the study.

Materials

Same as Experiment 3 with changing distractor only but each stimulus was 100 ms in length. As with Experiment 3, the number of pre-T1 defined the conditions; either three or six distractor items preceded T1.

Experimental design

The three repeated measures were, attention (focused vs. divided), T1-T2 SOA, (which correspond to lags 1, 2 and 9) and pre-T1 lead in (3 items or 6 items). Each participant completed focused and divided conditions. The experiment consisted of 48 trials for both the focused attention (3 blocks) and divided attention (6 blocks) conditions creating 288 trials in total.

Procedure

See General method

Results

The likelihoods of correct T2 identification for both attention conditions and collapsed across pre-T1 items is shown in Figure 4.1

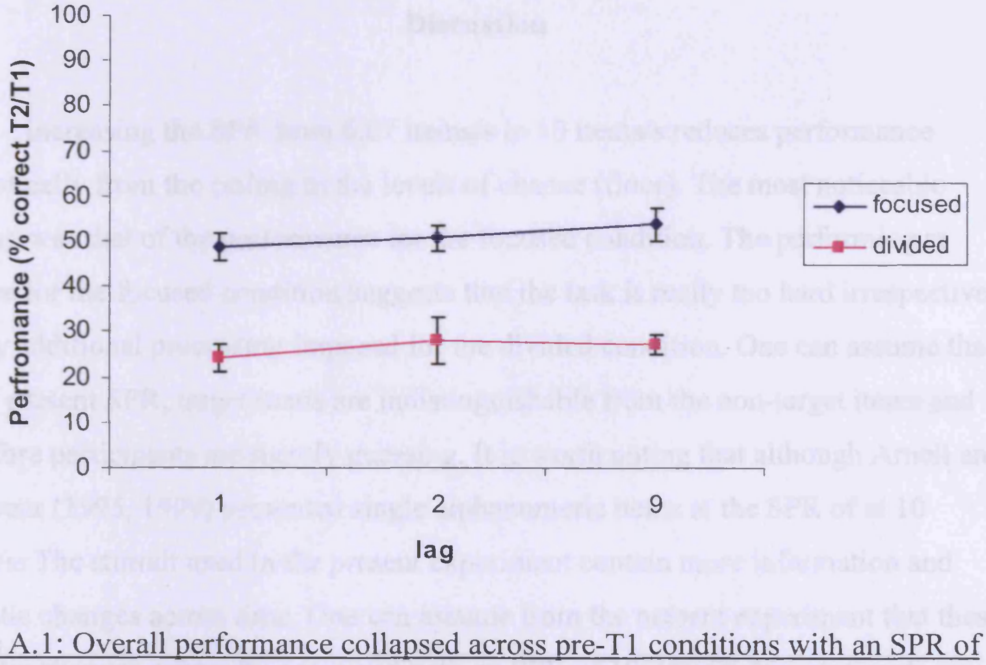

Figure A.1: Overall performance collapsed across pre-T1 conditions with an SPR of 10 items/s (error bars = +/- 1 mean standard error)

T1 performance: T1 was reported as correct on 53.4% of trials during the divided attention trials. A repeated measures ANOVA with number of pre-T1 items (2 levels), SOA (3 levels) was carried out on T1 performance and revealed no significant main effects or interactions (all p's > 0.5). This demonstrates that T1 performance was not affected by SOA or number of pre-T1 items. The task for T1 was 2 alternative forced choice (AFC) so therefore chance would be at 50%: participants seem to be at chance level.

T2 performance: The initial repeated measures ANOVA incorporating both pre-T1 conditions revealed only a significant main effect for attention $F(1,16) = 136.482$, $mse = 166.356$, $p < .001$, with all other main effects and interactions demonstrating no significant differences ($p > .05$). All that can be inferred from this analysis is that the task for the divided attention condition was more difficult and resulted in a significantly lower level of performance. Due to the lack of an interaction, no further analysis would be justified. From Figure A.1 is can be seen that performance does not vary due to SOA as is around the levels of chance for both attention conditions[8]. Additionally, no participants were excluded, as no participants were able to obtain the criterion level.

Discussion

Increasing the SPR from 6.67 items/s to 10 items/s reduces performance dramatically from the ceiling to the levels of chance (floor). The most noticeable finding was that of the performance for the focused condition. The performing at chance for the focused condition suggests that the task is really too hard irrespective of any additional processing imposed for the divided condition. One can assume that at the present SPR, target items are indistinguishable from the non-target items and therefore participants are merely guessing. It is worth noting that although Arnell and Jolicoeur (1995, 1999) presented single alphanumeric items at the SPR of at 10 items/s. The stimuli used in the present experiment contain more information and acoustic changes across time. One can assume from the present experiment that these acoustic changes cannot be perceived with an SPR of 10 items/s. If participants are going to be able to perform the task, the SPR needs to be increased

[8] The divided attention condition is a 2 AFC+ 2 AFC, so chance is at 25%.

Appendix 2

Below is provided a breakdown in performance from Experiment 6 according to number of pre-T1 items

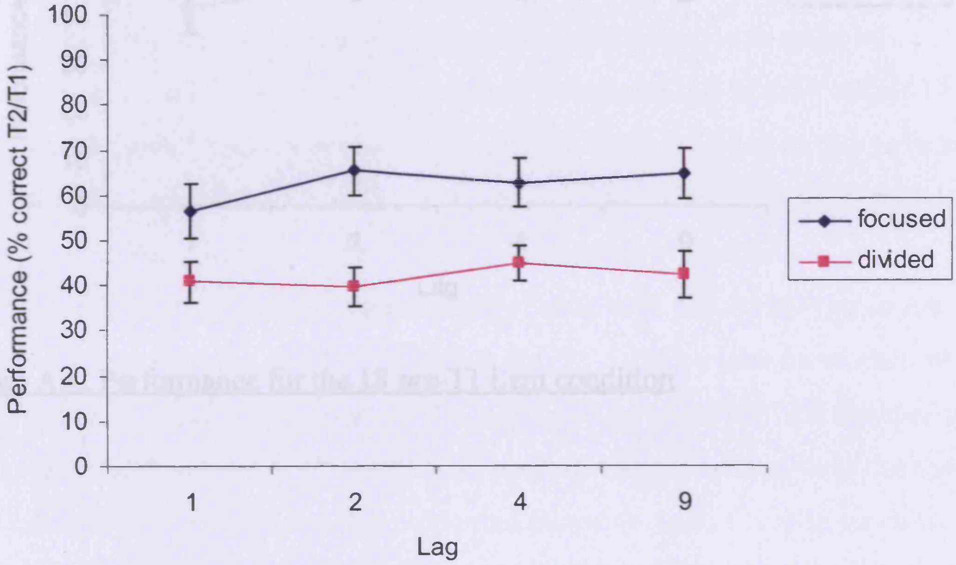

Figure A.2: Performance for the 0 pre-T1 item condition

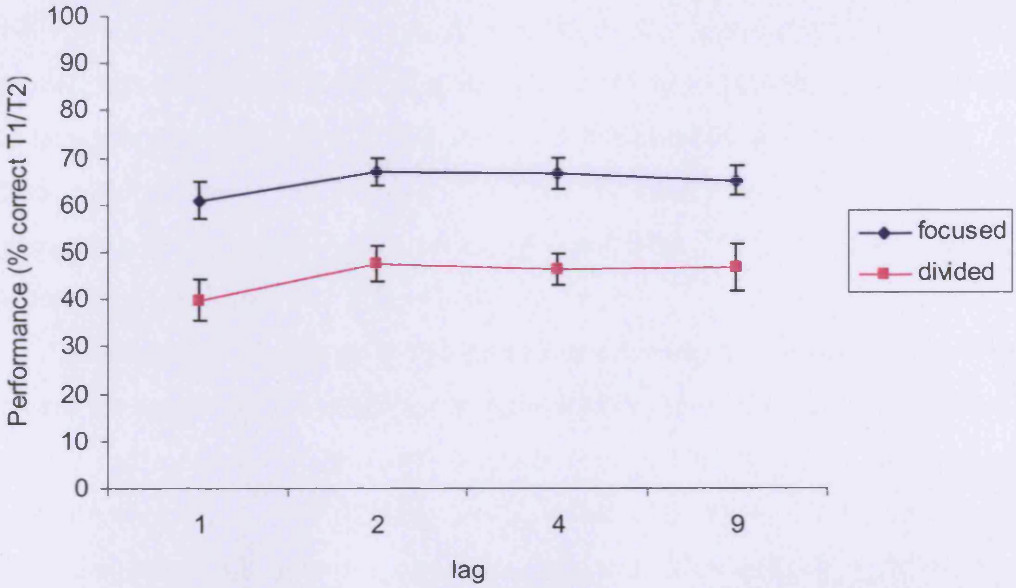

Figure A.3: Performance for the 9 pre-T1 item condition

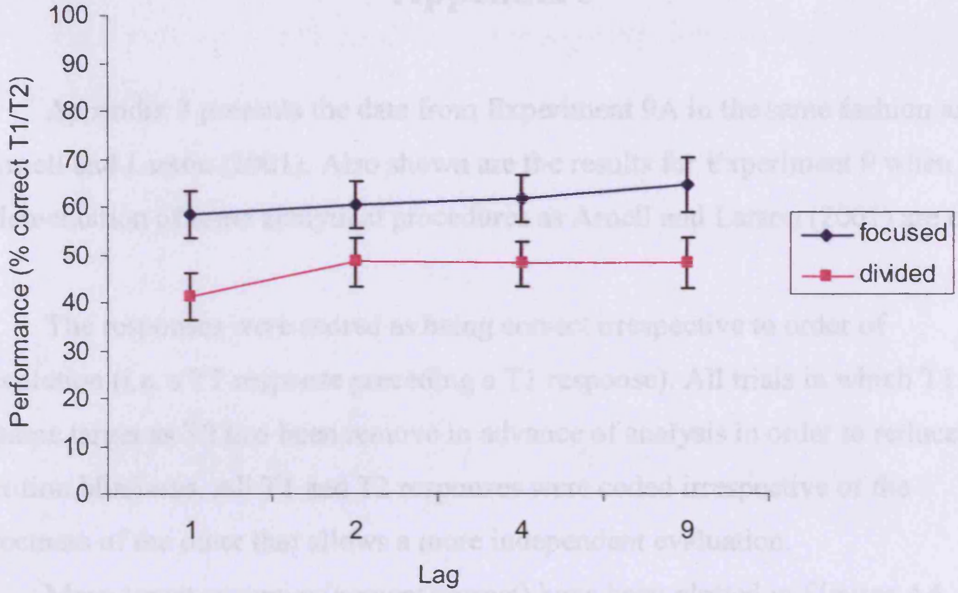

Figure A.4: Performance for the 18 pre-T1 item condition

Appendix 3

Appendix 3 presents the data from Experiment 9A in the same fashion as that of Arnell and Larson (2001). Also shown are the results for Experiment 9 when the implementation of same analytical procedures as Arnell and Larson (2001) are carried out.

The responses were scored as being correct irrespective to order of presentation (i.e. a T2 response preceding a T1 response). All trials in which T1 was the same target as T2 had been remove in advance of analysis in order to reduce repetition blindness. All T1 and T2 responses were coded irrespective of the correctness of the other that allows a more independent evaluation.

Mean target accuracy (percent correct) have been plotted in Figures A4, A5, A6 and A7 as a function of T1-T2 modality and T1-T2 SOA (similar method of presentation as Arnell and Larson 2001). Negative Lag indicates T1's distance from T2. Chance performance occurs at 25% for each modality combination. The mean target accuracy was submitted into a repeated measures ANOVA with modality (visual or auditory), target modality relationship (T1 and T2 modality both crossed and within), target number (T1 or T2), T1-T2 SOA as a within subjects analysis. The analysis revealed significant main effects for modality $F(1, 13) = 7.430$, $p<.05$, target modality $F(1, 13) = 7.172$, $p<.05$, target number $F(1, 13) = 106.463$, $p<.001$ and a significant main effect of SOA $F(4, 52) = 3.985$, $p>.05$. Significant interactions were revealed between modality and target modality $F1(1,25) = 10.016$, $p<.05$, modality and target number $F(1,25) = 52.724$, $p<.01$, modality and SOA $F(1,25) = 3.531$, $p<.05$. All interactions were significant (all ps<.05) apart from three-way interaction between modality, target modality relationship and SOA $F(4,52) = 2.341$, $p>.05$ and the four-way interaction $F(4,100) = 1.395$, $p>.05$.

To gain more insight as to the interactions subsequent analysis was performed on separate target modality relations in respect of target number and T1-T2 SOA. The within-modality auditory condition analysis provided a significant main effects of target number $F(1,13) = 13.820$, $p<.01$, SOA $F(4,52) = 4.229$, $p=.005$ and a significant interaction between target number and SOA $F(4,52) = 5.705$, $p=.001$. Separate analysis was carried out with respect to SOA and target number revealing a significant difference in performance across SOA for T1 $F(4,52) = 6.696$, $p<.001$ and a non-significant effect of SOA for T2 $F(4,52) = 2.367, p>.05$. Figure (A.4) showed performance is reduced at early lags (with targets presented within close temporal proximity), t-tests were carried out on the relationship between lag 1 for T2 and the later lag 3, $t\ (13) = -2.409, p<.05$.

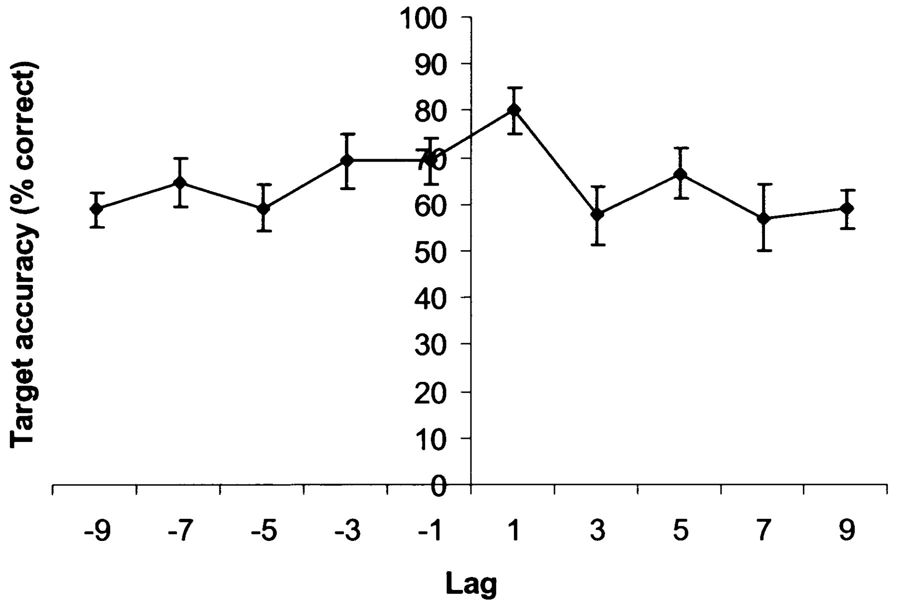

Figure A.5: Auditory within condition (auditory T1- auditory T2) mean correct responses as a function of target number. Note positive lag numbers equal performance of T2 as a function its relative temporal distance from T1, negative lags are vice versa concerning

The within-modality auditory condition analysis provided a significant main effects of target number $F(1,13) = 13.820, p<.01$, SOA $F(4,52) = 4.229, p=.005$ and a significant interaction between target number and SOA $F(4,52) = 5.705, p=.001$. Separate analysis was carried out with respect to SOA and target number revealing a significant difference in performance across SOA for T1 $F(4,52) = 6.696, p<.001$ and a non-significant effect of SOA for T2 $F(4,52) = 2.367, p>.05$. Figure (?) showed performance is reduced at early lags (with targets presented within close temporal proximity), t-tests were carried out on the relationship between lag 1 for T2 and the later lag 3, $t\ (13) = -2.409, p<.05$.

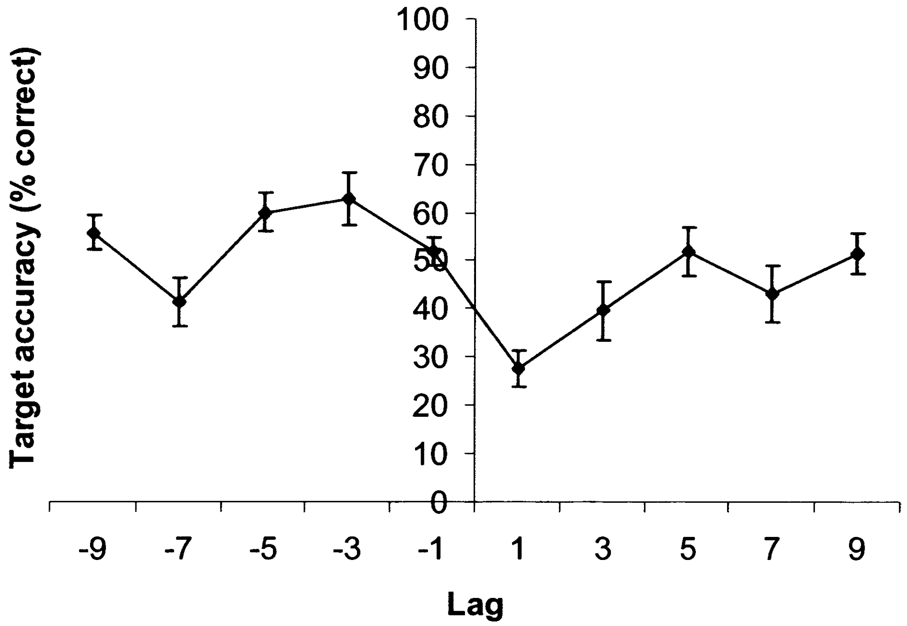

Figure A.6: Auditory crossed condition (auditory T1- visual T2) mean correct scored as a function of target number.

For the cross-modality visual (visual T1 and auditory T2) condition, a significant main effect of target number $F(1,14) = 153.407$, $p<.001$, SOA $F(4,52) = 2.549$, $p=.05$, and a significant interaction between target number and SOA $F(4,52) = 2.676$, $p<.05$. SOA in relation to target number revealed a non-significant difference across lag for T1 $F(4,52) = .950$, $p>.05$, but a significant effect of SOA for T2 $F(4,52) = 3.363$, $p<.05$. Further analysis using $t(13) = .647$, $p>.05$ showed lag-1 sparing was not present.

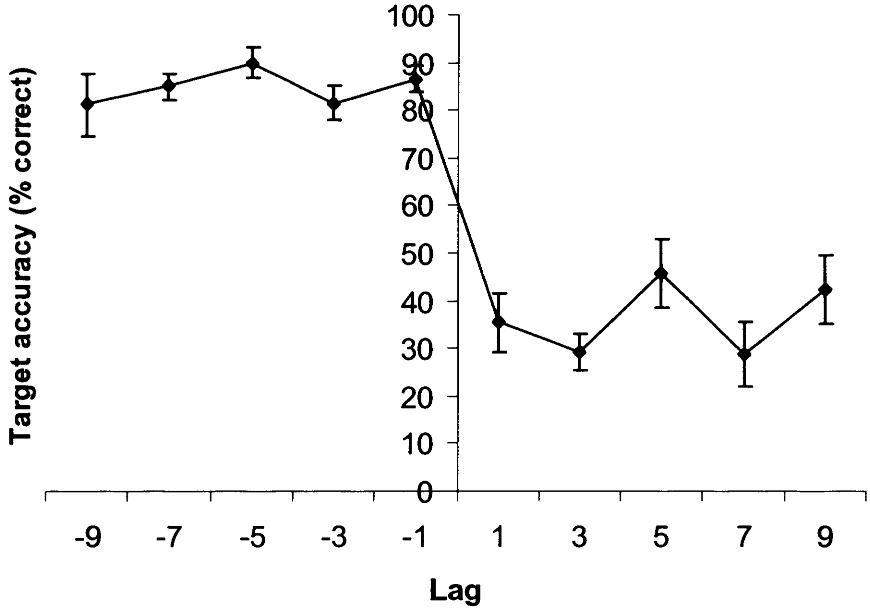

Figure A.7: Visual crossed condition (visual T1- auditory T2) mean accuracy plotted as a function of target number.

The within visual modality condition demonstrated a significant main effect of target number $F(1,13) = 22.547$, $p > .001$, SOA $F(4,52) = 3.684$, $p = .01$ and importantly target number and SOA interaction $F(4,52) = 10.332$, $p < .001$. The consequence of SOA was analysed separately for T1 revealing a non-significant effect $F(4,52) = 2.530$, $p > .05$, but a significant effect on T2 $F(4,52) = 10.904$, $p = .000$. Effects for lag-1 sparing were investigated using a paired samples t-test looking at T2 performance at lag 1 and lag 3, $t(13) = -.369$, $p > .05$.

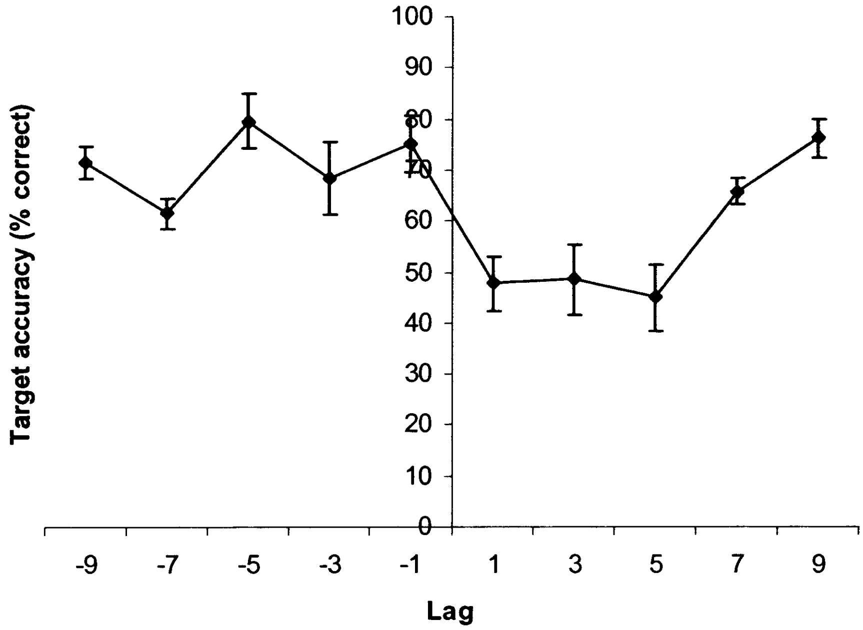

Figure A.8: Visual within condition (visual T1- visual T2) mean accuracy plotted as a function of target number.